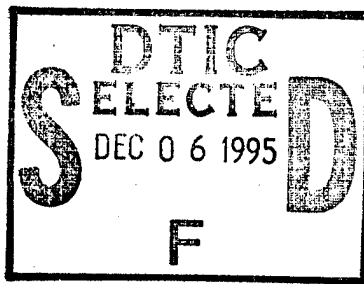Logistics Management Institute

Exploring the Multi-Link Concept for Defense Logistics Agency Requirements Determination

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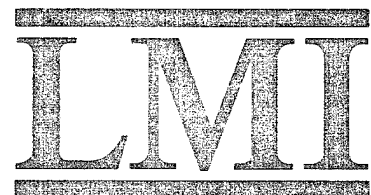
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Exploring the Multi-Link Concept for Defense Logistics Agency Requirements Determination

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Exploring the Multi-Link Concept
for Defense Logistics Agency Requirements Determination

Executive Summary

Each Military Service operates some form of multi-echelon supply system to provide spares and repair parts for maintenance. A multi-echelon supply system consists of a wholesale echelon and some number of retail echelons. The wholesale echelon procures stock from commercial suppliers or arranges for reparable items to be repaired at organic depots or by commercial contractors. Wholesale stocks support the retail system; however, those stocks are available only after some time elapses for ordering and shipping. For that reason, the retail echelon stocks supplies for immediate issue to retail maintenance depots.

A tradeoff exists between the amount of wholesale and retail stocks maintained. The more wholesale stock available, the less retail stock needed to support maintenance. Multi-echelon models have been developed to make that tradeoff, i.e., to determine the best mix of spares and where to put them. When those models are based on explicit weapon system availability goals, they are referred to as readiness-based sparing (RBS) models, and each Service has such a model tailored to its supply system. However, since data and operational control requirements make RBS models more difficult to use than the traditional single-echelon models, all Services except the Air Force use single-echelon models for replenishment sparing.

The Multi-Link concept is a way for the Services and the Defense Logistics Agency (DLA) to realize the benefits of RBS without requiring additional data collection or disrupting operational procedures to compute stock levels. Under the concept, a simplified RBS model would determine the proper response times the wholesale echelon should provide to the retail echelon in order to generate an optimal mix of wholesale and retail stocks. The wholesale echelon can then independently compute the stock levels required to meet those response time goals. With those response times, the retail RBS models can independently compute the retail stock levels it needs to meet operational availability goals. Thus, by using the "link" established by the wholesale response time, both wholesale and retail requirements systems can operate separately and yet achieve most of the benefits of a full-fledged RBS model.

Although, in theory, implementation of the Multi-Link concept will improve Service and DLA weapon system support, the concept has not yet been tested and a number of issues remain to be resolved prior to its use. This report

describes the concept starting with its functional basis and ending with a proposed strategy for DLA. Our primary findings and conclusions are as follows:

◆ Since the Multi-Link methodology focuses on line replaceable units (LRUs), the Services need to tell DLA which of its managed items are consumable LRUs so that its weapon system support program can focus on them.

◆ A Service weapon system manager is in the best position to run the RBS model for a weapon system but will need input from DLA on DLA-managed LRUs that are included in Multi-Link runs.

◆ In optimizing DoD-wide inventories to meet a weapon system operational availability goal, the Multi-Link methodology stresses stocking low-cost consumable LRUs managed by DLA rather than high-cost reparable LRUs managed by the Services. Thus, DLA items included under the Multi-Link umbrella must really be LRUs in order not to disrupt the stock levels of Service-managed LRUs.

◆ The Multi-Link concept requires increased wholesale supply performance for DLA's consumable LRUs, but

   ► the number of those items in a weapon system is small relative to the total number of DLA-managed items normally in a system and

   ► the investment in consumable LRUs is small compared to the investment in reparable LRUs.

Based on our findings and conclusions, we recommend the following actions to facilitate the use of the Multi-Link methodology:

◆ Until the Services start to use RBS models to compute retail levels for DLA-managed consumable LRUs, DLA should establish an appropriate and affordable supply performance target for the group of consumable LRUs in a weapon system. It should then use the basic safety level model to achieve that target and broadcast the resulting expected response times so that retail models can use them in stock calculations.

◆ Once the Services start to use the Multi-Link methodology and retail RBS models and include DLA-managed items, DLA should determine the affordability of Multi-Link goals, set supply performance accordingly, and broadcast that information to the Services for use in their retail models.

To facilitate improved readiness support through the proper application of the Multi-Link concept, DLA and the Services should establish ground rules for governing Multi-Link procedures and responsibilities, perhaps through memorandums of agreement.

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CHAPTER 1

Introduction

In this report, we describe the Multi-Link process for computing readiness-based stock levels for secondary items and how the Defense Logistics Agency (DLA) should use that approach to build inventory levels for its essential weapon system items.

BACKGROUND

Currently, the Joint Logistics Systems Center (JLSC) is developing a standard DoD materiel management system for use by all DoD Components, including DLA. As part of that effort, it has adopted a strategy that includes a new "Multi-Link" approach for setting inventory levels for weapon system items. Under this approach, wholesale response time goals for essential weapon system items are determined by a simplified multi-echelon, operational availability (A_o) model.

As illustrated in Figure 1-1, the "link" in Multi-Link refers to the Multi-Link-generated, A_o-based wholesale response time goals that link the requirements determination models in wholesale and retail systems and also ties the response times of those systems to weapon system readiness. "Multi" refers to the fact that the link is between multiple echelons of supply and their respective requirements determination models.
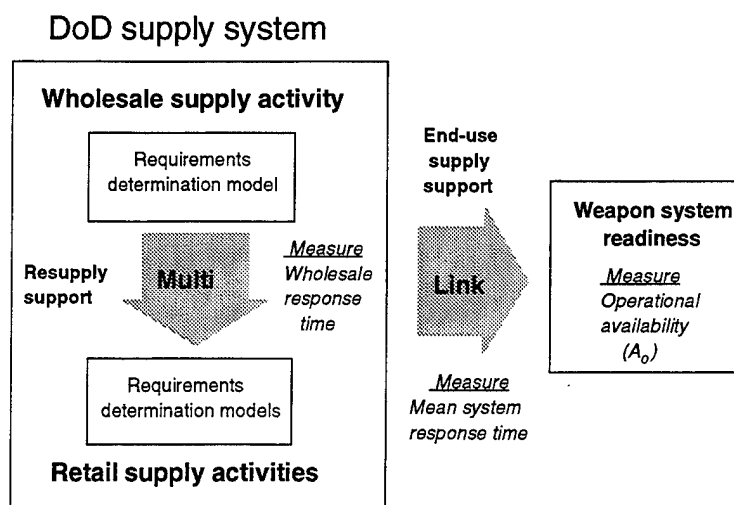
Figure 1-1.
Linking Wholesale and Retail Support to Achieve Weapon System Readiness

The Military Services, to varying degrees, have developed methods to determine the minimal-cost inventory they need to meet their weapon system availability goals. By necessity, those methods, which are referred to as readiness-based sparing (RBS) models, have multi-echelon and multi-indenture capabilities.

A multi-echelon capability is needed since weapon system downtime due to supply occurs when the echelon at which the weapon system is repaired does not have the needed spare part. Since higher echelon inventory supports the lower echelons, the better that support, the less inventory the lower echelons will need. However, because of lead times, higher echelon inventory is limited in its ability to support demands at the lower levels. Generally, the lower echelon will need to hold some inventory no matter how much higher echelon inventory is in the system. Models with a multi-echelon capability can determine the proper placement of inventory so that overall inventory expenditures are kept to a minimum.

Only shortages of items that are removed and replaced directly on the weapon system cause weapon system downtime. Those items are called line replaceable units (LRUs) by the Army and Air Force and weapon replaceable assemblies (WRAs) by the Navy. A multi-indenture capability is needed because other weapon system parts are used in some manner to repair LRUs and thus have a secondary effect on weapon system readiness. The greater the stock of non-LRUs, the less stock of LRUs needed. However, because LRUs take time to repair, the effectiveness of non-LRUs in preventing LRU shortages has a finite limit. Models with a multi-indenture capability are able to make the tradeoffs between the LRUs and non-LRUs.

The Multi-Link process retains the multi-echelon and multi-indenture features of a full-scale RBS model but does so with a minimal amount of data and minimal disruption to existing operational procedures governing requirements computation. As we show in this report, the heart of the Multi-Link process is an RBS model stripped to its essentials. That model will approximate the wholesale echelon response time that a full-blown RBS model would produce. A link is established to the wholesale echelon through response time targets for wholesale items. After the wholesale echelon uses the targets to compute requirements, a second link is established with the retail echelon by publishing the expected wholesale item response times. Because of constraints and other factors, on some occasions, the wholesale level may be unable to achieve the original Multi-Link response time goals.

The Air Force already has an RBS model and its supporting infrastructure is in place for reparable items. Thus, only the Army, Navy, and DLA are considering how to use the Multi-Link approach. At a later date, the Air Force may decide to use the Multi-Link approach for consumable items.

Although DLA does not manage any weapon systems, it does manage essential weapon system consumable items.[1] For example, DLA manages cockpit indicator lights on Army, Navy, Air Force, and Marine Corps aircraft. With its weapon system support program (WSSP), which has been active for some time, DLA has strived to improve, or at least maintain, its support for weapon system items. At one time, it augmented the safety levels of demand-based items in the WSSP to ensure a high level of protection against stockouts. Most recently, as its budgets were reduced, DLA sought to protect essential WSSP items by not reducing their levels to the extent that it reduced levels for non-WSSP items. However, such tactics were directed at achieving high supply availability goals for those items and not at achieving specific readiness goals for the weapon systems they support.

Admittedly, higher supply availability goals for WSSP items should improve the readiness of the weapon systems they support. However, the linkage between supply availability and weapon system readiness has not been made. Consequently, an approach that is based solely on higher supply availability goals might result in a high cost for weapon system support.

Although the Multi-Link approach should theoretically improve DLA's weapon system support, it is untried and a number of issues need to be resolved prior to its use. The most critical issue that DLA will face is identifying consumable LRUs. Current procedures for doing that are clearly imperfect and tend to identify too many consumable items as LRUs. Over-identification can reduce the inventory levels for the Service-managed reparable items causing potentially serious readiness problems. Thus, DLA must be cautious when deciding how to use the Multi-Link process. Because of our experience with A_o modeling, we were asked to assist DLA in determining the role of the Multi-Link process in computing levels for the DLA-managed weapon system items.

PURPOSE

This study defines how the Multi-Link process should apply to DLA supply-management, analyzes proposed alternatives under the Multi-Link process, and examines options for resolving concept implementation issues.

SCOPE

To develop the Multi-Link capability, JLSC established a Multi-Link project involving all Components. In providing support for this project, JLSC issued a general statement of work containing the specific tasks shown in Table 1-1.

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[1] A discussion of essential weapon system consumable items is presented in LMI Report DL101R1, *Weapon-System-Oriented Supply Management at DLA: Relating Inventory Investment to Readiness*, Christopher H. Hanks, March 1993.

Table 1-1.
JLSC Multi-Link Tasks

Task	Description
1	Compare one-way link with two-way link
1a	Evaluate the Aircraft Availability Model (AAM) to provide link
2	Define the data requirements
3	Investigate the treatment of demand classes
4	Develop an approach for common items
5	Evaluate the demonstration issues
6	Estimate the budget impact
7	Adopt SESAME to CARES/SPA *(not applicable to DLA)*

Note: SESAME = Selected Essential Stockage for Availability Method (Army); CARES/SPA = Computation and Research Evaluation System (Navy) / Supply Performance Analyzer (Army).

In accordance with the six tasks applicable to DLA, we performed the following actions:

◆ We examined the proposed alternatives for implementing the Multi-Link concept as they would apply to DLA items. In particular, we analyzed demand class treatment, common item considerations, and cross-Component and internal DLA demonstration issues. Those actions respond to JLSC Tasks 1, 3, 4, and 5.

◆ We helped define data and processing requirements and identify data sources in support of Multi-Link methodologies. Those actions respond to JLSC Task 2.

◆ We worked with responsible Service activities to identify the probable impacts of using the Multi-Link process. Those actions respond to JLSC Task 6.

We used several Army and Navy weapon systems to work through these actions and demonstrate Multi-Link concepts. (Appendix B provides a brief description of each of the systems.)

REPORT ORGANIZATION

In Chapter 2, we discuss how materiel management of secondary items affects weapon system readiness and how DoD policy has changed to include operational availability in the requirements determination process for secondary items. Chapter 3 describes the Multi-Link process and how it should enhance secondary item support to weapon system readiness; it also describes the Multi-Link capabilities being developed. Chapter 4 then addresses the issue of what items are candidates for Multi-Link computations and how they can be

identified. In Chapter 5, we report on an exercise conducted with our test weapon systems to estimate the supply performance and cost implications of using the Multi-Link process. Finally, Chapter 6 presents some implementation issues and offers options for dealing with them.

CHAPTER 2

Weapon System Readiness and Secondary Item Materiel Management

Materiel management in DLA is commodity oriented, and decisions are often made on a commodity basis without fully considering their effect on the readiness of weapon systems. The Multi-Link process offers DLA the opportunity to include weapon system readiness in its materiel management decision-making. Thus, in this chapter, we define the terms and concepts involved in relating secondary item management to weapon system readiness.

WEAPON SYSTEM DESCRIPTION

Although the term weapon system is commonly associated with military aircraft, ships, missiles, and combat vehicles, it has no official definition. The difficulty in defining a weapon system may be illustrated by a ship, which could be defined narrowly as a collection of weapon systems or broadly as a weapon system. As shown in Figure 2-1, a ship has a variety of missions, each requiring a number of systems to perform.
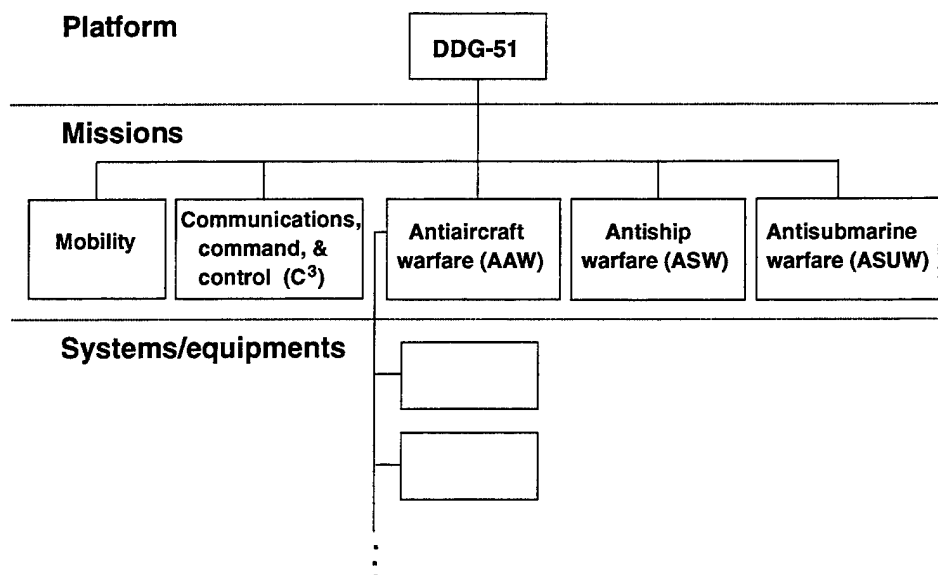
Figure 2-1.
Guided Missile Destroyer — A Weapon System or a Collection of Weapon Systems?

At the narrowest level, the term weapon system could apply to the total ship or platform. However, to a Navy program manager looking at the readiness of the ship in terms of its ability to perform each of its assigned missions, the collection of equipment needed to perform each mission forms a weapon system. And, to a Navy equipment manager, each of the systems supporting a mission area is a weapon system.

The DLA WSSP offers a broad definition of a weapon system as any Service-nominated end item or any Service-nominated group of items. An end item is defined as "a final combination of end products, component parts, or materials ready for its intended use (e.g., a ship, tank, mobile machine shop, or aircraft)."

However, for our purposes, we consider a weapon system to be any system that is suitable for readiness-based requirements determination modeling. To satisfy our definition, a weapon system must satisfy the following two prerequisites:

◆ It must have a readiness goal (either within or constrained by a budget).

◆ It must have a configuration record that identifies items, their indenture, their mission essentiality, and their level of maintenance.

The inventory levels for items associated with any end item or group of items that does not have these attributes cannot be computed using a readiness-based model.[1]

In the remainder of this chapter, we focus on the first prerequisite, that is, the readiness aspects of relating the inventory requirements determination process to weapon system performance. In Chapter 4, we discuss the second prerequisite.

WHAT IS WEAPON SYSTEM READINESS?

In assessing the readiness of a weapon system, a unit commander considers equipment availability (i.e., has the system been issued to the unit?), personnel readiness (i.e., are people available and trained to operate the system?), and materiel readiness (i.e., are there requirements for items that comprise the system and are replacements for those items available?). In January 1993, the Office of the Assistant Secretary of Defense (Production and Logistics) issued DoD 4140.1, *DoD Materiel Management Regulation*.[2] In that regulation, weapon system readiness is defined as:

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[1] Although not considered yet by JLSC, Multi-Link concepts could be extended to any group of items that has a retail supply performance goal in lieu of a weapon system readiness goal.

[2] Since it consolidated many previous directives, instructions, regulations, and manuals, DoD 4140.1-R is often referred to as *Super Reg*.

A measure or measures of the ability of a system to undertake and sustain a specified set of missions at planned peacetime and wartime utilization rates. Measures take account of the effects of system design (reliability and maintainability), the characteristics of the support system, and the quantity and location of support resources. Examples of system readiness measures are combat sortie rate, fully mission capable rate, and operational availability.

By highlighting item reliability, maintainability, and supportability, that definition focuses on materiel readiness rather than personnel readiness and equipment availability. It reflects the fact that materiel readiness has become the focal point of weapon system readiness in materiel management.

Although the cited regulation is new, DoD logisticians have for some time sought to relate inventory requirements determination to materiel readiness, and that desire has spurred the development of operational availability (A_o) models. Those models compute inventory levels for essential items on the basis of those item's contributions to the A_o of weapon systems. The universal development of these models by the Services has made A_o the de facto measure of readiness used in requirements determination modeling.

WEAPON SYSTEM READINESS GOALS

Operational availability (A_o) is defined as the percent or fraction of time a weapon system is ready to perform its assigned missions. Mathematically, it is computed as:

$$A_0 = \frac{time\ that\ the\ weapon\ system\ is\ ready\ to\ perform}{total\ time\ that\ the\ weapon\ system\ is\ available}.$$

For example, if a weapon system is able to perform 584 hours out of the 730 hours in a typical month, its A_o would be 0.8 or 80 percent.

Although the Services quantify A_o in similar ways, they employ different approaches in setting A_o goals. The Joint Chiefs of Staff (JCS) uses reports from the status of resources and training system (SORTS) to track military readiness. Under SORTS, "category levels," or "C-levels," reflect a reporting unit's readiness to perform its wartime missions. Table 2-1 lists the SORTS criteria for C-level from C-1 to C-5 (with C-1 being the highest level and C-5, the lowest) for combat-essential equipment, aircraft, and major end items. Army and Marine Corps ground units use C-ratings to evaluate their readiness and as goals for their weapon systems.

On the other hand, the Air Force has individual aircraft A_o requirements goals, which are generally higher than the 75 percent availability goal SORTS prescribes for aircraft.

These A_o goals have been established solely for the purpose of the Air Force's worldwide requirements computation and may not reflect the actual A_o's experienced by the Air Force.

Table 2-1.
SORTS Readiness Criteria

Equipment	C-1 (%)	C-2 (%)	C-3 (%)
Combat	90	70	60
Aircraft	75	60	50
End item	90	70	60

The Navy has individual aircraft goals that differ by type of unit (e.g., deployed units have a goal that is 5 percent higher than that for nondeployed combatant aircraft). Currently, ships and ship mission areas are not assigned goals because of the multiple levels of weapon systems on a ship. However, shipboard systems do have individually assigned goals. Table 2-2 lists the A_o goals for several weapon systems.

Table 2-2.
Operational Availability Goals for Demonstration Weapon Systems

Weapon system	A_o (%)	Weapon system	A_o (%)
Army MLRS	90	Navy close in weapon system	90
Army UH-60A helicopter	75	Navy machine control system	90
Army M-1 tank	90	Navy SH-60F helicopter	60
Army Bradley fighting vehicle	90	Air Force F-16 aircraft	84
Army SINCGARS	90	Air Force E-3A aircraft	83
Army howitzer	90	Air Force MH-60G helicopter	75

Note: MLRS = Multiple Launch Rocket System; SINCGARS = Single Channel Ground Airborne Radio System.

How does the use of A_o goals change materiel management? The following differences arise from setting and managing towards A_o goals instead of setting and managing toward traditional supply performance goals (i.e., supply availability, average customer waiting time):

◆ Weapon system managers, who may or may not be located at Service inventory control points (ICPs), set A_o goals, while commodity managers, who are located at Service and DLA ICPs, set supply performance goals.

◆ An A_o goal implicitly considers the performance of both retail and wholesale levels of supply, while a supply performance goal is generally only concerned with performance at a single echelon of supply.

◆ While only a single supply performance goal would apply to an individual item, several A_o goals may apply to an item common to several weapon systems.

In summary, A_o is a measure of weapon system performance rather than a measure of supply system performance, and weapon system A_o goals are established outside the DoD supply system.

How Secondary Items Contribute to Readiness

Although A_o is not a measure of supply system performance, it is related to supply system performance. That relationship is based on the contribution of secondary items to weapon system performance.

A weapon system is considered operational or ready when it can perform its assigned job. It is "down" or not operational when it cannot perform because one or more essential item (either reparable assemblies or consumable parts) fail and need to be replaced. To get replacements, the supporting maintenance element places demands on the supply system. Those demands are either filled immediately or are backordered, depending on the range and depth of stock maintained by the supply system. If they are backordered, the maintenance element must wait until the supply system fills that backorder. The time that the supply system takes to respond to demands for essential items therefore directly affects the readiness of a weapon system.[3]

Modeling Item Support

The level of inventory for an item affects the time that the supply system requires to respond to a customer demand for that item in two ways. First, it governs the number of demands that can be filled immediately (i.e., the item's fill rate or supply availability). Second, it limits the time that the customer must wait for demands that are not filled immediately (i.e., the item's backorder time).

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[3]Not all weapon system downtime is the fault of supply; maintenance time to remove and replace faulty components is also considered downtime. Therefore, even if an infinite level of stock were available to reduce awaiting parts time to zero, the A_o for the weapon system would still be less than 100 percent. Inherent availability (A_i) measures weapon system readiness assuming no time is spent awaiting parts and, as such, represents an upper bound on weapon system A_o.

The combination of these two measures is called an item's mean system response time (MSRT).[4] Mathematically, MSRT is given by:

$$MSRT = kf + (1 - f)b_t$$

where

f = fill rate,

k = time to make an immediate issue, and

b_t = average time on backorder.

The time to make an immediate issue is normally assumed to be zero. And "$1 - f$" is the backorder rate, which is also given by the number of backorders established divided by total demand. Since the number of backorders established times the average time on backorder equals the expected number of backorders on-hand, we can express MSRT as follows:

$$MSRT = (EBE_i / d_i)(b_t) = EBO_i / d_i,$$

where

EBE_i = expected number of backorders established for item i,

d_i = total demand for item i, and

EBO_i = expected backorders on-hand for item i.

The model prescribed in the old DoD Introduction (DoDI) 4140.39, *Procurement Cycles and Safety Levels for Secondary Items,* was an MSRT model in that it sought to minimize costs while meeting a population-wide constraint on expected backorders (EBOs) (which is equivalent to constraining the MSRT).

Readiness-based sparing[5] is defined as

"The establishment of an optimum range and quantity of spares and repair parts at all stockage and user locations in order to meet approved, quantifiable, weapon system readiness, operational availability, or fully mission-capable objectives."[6]

By the above definition, an A_o model is an RBS model. Like an MSRT model, an RBS, an A_o model targets on response time in terms of item EBO. The difference between an RBS model and the model prescribed in the old DoDI 4140.39 is

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[4] Unfortunately, this terminology is not standard and the terms "mean logistics response time (MLRT)," "average customer waiting time (ACWT)," and "mean supply delay time (MSDT)" are also used.

[5] RBS is also referred to as sparing-to-availability (STA).

[6] DoD 4140.1-R, pp. L-19 and L-20.

in how the RBS model uses MSRT or EBO values to develop inventory levels that support estimated A_o values.

Three principal A_o estimators are used by RBS models (Equations 2-1, 2-2, and 2-3):

$$A_0 = \frac{MTBF}{MTBF+MTTR+MSRT},$$ [Eq. 2-1]

where

MTBF = mean time between failures, and

MTTR = mean time to repair.

$$A_0 = \prod_{i=1}^{N} \left(1 - \frac{EBO_i}{QPA_i \times NW}\right) QPA_i,$$ [Eq. 2-2]

where

N = number of essential LRU items in the weapon system,

QPA_i = quality per application (weapon system) for item i, and

NW = number of weapons.

$$A_0 = 1 - \sum_{i=1}^{N} (impact\ factor)\left(\frac{EBO_i}{NW}\right),$$ [Eq. 2-3]

where an impact factor is the ratio of item downtime to weapon system downtime.

We present more information on these three estimators in Appendix C. We discuss the current DoD RBS models subsequently in this report under the discussion of A_o modeling.

Readiness Support in Initial Sparing or Provisioning

Initial sparing or provisioning refers to setting stock levels for an item new to the DoD supply system or for an established item with a new application (i.e., an item already in the DoD supply system that will be part of a new weapon system or new assembly within a system). DoD 4140.1-R prescribes the use of readiness-based sparing for weapon system provisioning except "when it is not economical or procedurally feasible" in which case "demand-based requirements determination methodologies may be used."

That requirement means that the initial item inventory levels for a new weapon system should be based on an A_o goal for that weapon system. Equally

important, the regulation goes on to state that safety level quantities are not authorized when using demand-based methodologies but are authorized for readiness-based methodologies. The purpose of an item's safety level is to control the response time for an item by protecting against variances in demand and lead time during a procurement. Consequently, when provisioning, DoD logisticians can only affect supportability by using readiness-based methodologies to determine item inventory levels.

Readiness Support During Replenishment

Replenishment refers to actions to resupply or increase stockage of reparable or consumable items in support of fielded weapon systems. Unlike provisioning, which seeks to stock an initial level of items sufficient to meet future demand, replenishment seeks to maintain stock levels subject to changing demands and resupply times. If demand and resupply times remain relatively constant, replenishment levels should be the same as provisioning. However, since demand-based safety levels are authorized during replenishment, DoD logisticians can affect supportability by using either readiness-based or demand-based methodologies, and as noted, the only difference between the two is how item response time is included in the formulation of the inventory model.

READINESS-BASED INVENTORY LEVELS

In the following subsections, we review the requirement to compute readiness-based levels, how A_o models compute readiness-based levels, how readiness-based levels differ from traditional levels, and how wholesale supply support changes with readiness-based levels.

The Requirement to Relate Inventory Levels to Weapon System Readiness

The requirement to relate the materiel management of secondary items to weapon system readiness comes from DoD 4140.1-R:

"*a.* For secondary items that are essential to weapon system performance, the DoD Components shall normally compute requirements with mathematical models that relate range and depth of stock to their effect on the operational availability of the weapon system. These models should be capable of:

(1) Optimizing support to achieve weapon system readiness goals for the least cost.

(2) Maximizing weapon system readiness for a specified level of funding. Where data availability and model capabilities permit, such models shall be multi-echelon and directly compute both the range and depth for all stockage levels."[7]

Although the retail echelon of supply that directly supports a weapon system has the greatest impact on weapon system's A_o, a multi-echelon A_o model is desirable because it optimizes stock throughout the supply system and not just at one location.[8]

Operational Availability Modeling

Although the new guidance given in DoD 4140.1-R is a change from previous policy issuance that talked to time-weighted, requisition-short requirements levels,[9] it reflects the Services growing use of A_o-based requirements models since the 1970s.[10] Table 2-3 lists the principal models that the Services are currently using readiness-based requirements.

Table 2-3.
Service to Operational Availability Models

Service	Model	Application	Developer
Army	Selected Essential-Item Stockage for Availability MEthod (SESAME)	Retail provisioning of new weapon systems.	Army Inventory Research Office of Army Materiel Systems Analysis Activity (AMSAA)
Navy	TIGER/Availability Centered Inventory Model (ACIM)	Retail allowance lists for shipping end items.	CACI
	Aviation Readiness Requirements Oriented to Weapon Replaceable Assemblies (ARROWs)	Retail allowance lists for aircraft.	Navy Fleet Materiel Support Office
Air Force	Aircraft Availability Model (AAM)	Wholesale and retail replenishment levels for weapon system depot-level reparable items.	Logistics Management Institute (LMI)

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[7] Chapter 3, *Requirements*, pp. 3-1 and 3-2.

[8] Since Multi-Link deals specifically with setting wholesale levels of stock, we have included wholesale in our definition of multi-echelon. However, a model that sets levels of stock for more than one retail echelon of supply is also a multi-echelon model.

[9] The new regulation states that the range and depth of stocks of items that are not essential to a weapon system should be based on customer waiting time. In terms of requirements modeling, no difference exists among time-weighted, requisition-short, and customer requisition waiting time.

[10] For a review of the early history of A_o modeling in the DoD, see the Navy Fleet Material Support Office Report 160, *Overview of Multi-Echelon Models*, J.A. Mellinger, November 1984 (DTIC AD-A149 615).

Except for the Air Force model, which calculates wholesale and retail levels of stock for depot level-reparable items, the Service A_o models have been principally concerned with retail inventory levels. Under the Multi-Link concept, these models would either be extended to consider wholesale inventory levels or connected to wholesale requirements models. No new model is being developed for Multi-Link processing; existing models are being modified.

HOW AN RBS MODEL WORKS

Current RBS models use marginal analysis as their method of optimization. The standard marginal analysis approach is as follows:

- For each item, calculate a cost and benefit ratio for adding a spare to item's inventory level.

- Rank the items by their ratios.

- Select the spare with the most improvement for the cost.

- Recalculate the cost and benefit ratio for the next spare for the item selected, and rerank the item according to its new ratio.

- Repeat the previous two steps until the A_o goal is reached or until the cost limit is reached.

As mathematically demonstrated in LMI Report AF201, *The Aircraft Availability Model: Conceptual Framework and Mathematics*, T. J. O'Malley, June 1983, this approach yields an optimal list of spares. The Army SESAME uses a slightly different marginal analysis approach, employing sophisticated algorithms to obtain the optimal value for the cost of backorders (lambda), the equivalent of the cutoff value for the cost/benefit ratio. Both approaches should yield the same list of spares for a point on the A_o and inventory cost curve.

SPECIAL FEATURES OF AN RBS MODEL

When computing an item's impact on A_o, an RBS model must consider the position of the item in the weapon system's configuration. A first-indentured item goes directly on the end item and is removed and replaced by the maintenance element directly supporting the weapon system.[11] A second-indentured item goes on a first-indentured item. If an item is at the top of hierarchy (i.e., a

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[11] Typically, the organizational level of maintenance directly supports a weapon system. However, an operating weapon system can be worked on by an intermediate level of maintenance such as is the case in the Army, where direct support units remove and replace first-indenture items on tanks and other combat vehicles.

first-indentured item), its effect on A_o is more direct and consequently greater, than if it is lower in the hierarchy (i.e., second-, third-, etc., indentured items).[12]

For example, a spare for a second-indenture item will reduce the repair time for its associated first-indenture item, which will, in turn, reduce the time the system or end item is not available when the first-indenture item fails. On the other hand, a spare for the first-indenture item will directly reduce that time. At a minimum, an RBS model must deal with essential first-indentured items. If it also considers items that are at lower levels of indenture, it has a multi-indentured capability.

An RBS model must also treat the echelon of supply that is directly supporting the weapon system. A single-echelon RBS model would therefore be a "retail" model. (A "wholesale" single-echelon RBS model is not possible by definition.) However, if an RBS model also treats the higher echelon of supply, it has a multi-echelon capability. The optimization process for a multi-echelon model not only trades off between items when selecting a spare but also considers the best location for that spare among all the echelons of supply supporting the system or end item.

Readiness-Based Levels Compared with Traditional Levels

An A_o model is a range and depth model in one. That is, it computes the depth of stock required to meet an A_o or cost goal for an item, and if that depth is zero, the item is not stocked.

In DLA, rules for range and depth of stock are separate. The current range rule is based on the number of demands for an item in a period of time, and the current depth rules depend on the type of item being stocked. For a low-demand item with no demand forecast, the depth of stock revolves around rules that compute a single level called the numeric stockage objective (NSO) quantity. Hence, such items are referred to as NSO items. For an item with a demand forecast, the depth of stock is based on the computation of three requirements levels: the economic order quantity (EOQ), the lead time demand quantity, and the safety level quantity. Items with those levels are referred to as quarterly forecasted demand (QFD) items.[13]

As previously noted, DLA computes and maintains safety levels for its QFD items to achieve a performance goal. The new readiness-based sparing policy does not call for any new levels; rather, it directs that the safety level goal for essential weapon system items should be based on A_o and not customer waiting

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[12] The exception is when a lower indentured item is treated as a first-indentured item. For example, if direct support maintenance removes a first-indenture item to remove and replace a second-indenture item that has failed, the second-indenture item is being treated as a first-indenture item and its effect on A_o is the same as that of a first-indenture item.

[13] A QFD item may actually be forecasted monthly or quarterly. In either case, however, the result of the forecast is a QFD.

time or supply availability. In short, the levels are the same except that the safety levels themselves may have different values.

How Wholesale Supply Support Changes Under A_o Modeling

Wholesale supply support is directed at satisfying requisitions from retail activities. Its objective is to provide the right materiel at the right place at the right time and at the lowest cost. This aspect of wholesale supply support does not change with the move from traditional requirements modeling to A_o modeling.

What does change is how supply support is measured and how safety stocks are distributed across weapon system items. DLA has traditionally used supply availability (i.e., percent of requisitions filled immediately) as its principal measure of supply support. Its safety level formula is derived from a cost equation that has the expected number of system backorders as the target of a performance constraint. Under this formula, items with low unit costs and large lead-time demand variances get more safety stocks than items with high unit costs and low variances.

Under A_o modeling, wholesale responsiveness to customer requisitions is still at the center of levels computations and the formulas include all of the item data elements that are in the current formula (e.g., unit price, lead-time, and demand variance). However, the formulas also consider the contribution of the item to the readiness of the weapon system. The result is that safety stocks tend to be more evenly spread across all essential items. Items with low unit costs and large lead-time demand variances will tend to get more safety stocks. But the differences among item safety levels will tend to be smaller and the range of items getting safety stocks may be larger.

CHAPTER 3

Description of the Multi-Link Process

New DoD policy guidance on materiel management requires the Components to use models that relate range and depth of stock to operational availability (A_o) when computing requirements for essential weapon system items. The Air Force currently uses such a model to compute system-wide requirements for its depot-level reparable items but not for the consumable items it manages. The other Components, however, are not prepared to use the Air Force model. Accordingly, JLSC is developing the Multi-Link process as another means of computing readiness-based requirements levels for essential weapon system items.

THE JLSC STRATEGY FOR DETERMINING REQUIREMENTS

In formulating its requirements strategy for DoD's future standard materiel management system, JLSC sought full compliance with DoD policy. However, it also recognized that the current state-of-the-art in requirements modeling does not provide for a multi-echelon, A_o solution for all types of items for all categories of weapon systems. Hence, it adopted the following three-pronged strategy for computing requirements:

♦ For items that are not essential weapon system items, use the current capability, which is based on customer waiting time.

♦ To accommodate high-management-intensity items,[1] use the current capability to compute multi-echelon, A_o requirements.

♦ For other essential weapon system items, provide for a new capability that links wholesale response time goals to weapon system A_o.

The third capability is the Multi-Link process.

The output of the Multi-Link process is wholesale response time and not mean system response time. By definition, the term "mean system response time" refers to the response time of the DoD supply system and is the time that the end user must wait for a weapon system item. Under the Multi-Link process, mean system response time would be the target of the retail A_o model, while wholesale response time would be the target of the wholesale customer waiting time model and an input to the retail A_o model. The term "average customer waiting time" refers to response time at any echelon.

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[1] LMI Report CC201LNI, *Evaluation of Alternative Approaches to Developing the Requirements Determination Standard System*, Richard Allen, et al., October 1994.

THE MULTI-LINK CONCEPT

The benefits from multi-echelon A_o modeling are either a minimum total investment in wholesale and retail stock to achieve a specified weapon system A_o goal or the maximum A_o for a given level of investment. Of the A_o models currently in use, the Air Force Aircraft Availability Model is the only true wholesale/retail multi-echelon A_o model. However, it has its limitations.

◆ It does not deal with consumable items.

◆ It assumes all retail sites are identical.

◆ It has a limited capability to handle redundancy.

◆ It has larger data requirements and processing needs than other wholesale models.

To gain the benefits of multi-echelon A_o modeling, at least for its most expensive items (i.e., its depot-level reparable items), the Air Force has accepted those limitations. However, the other Services are not satisfied with them and have pursued alternative approaches, one of which is now known as the Multi-Link approach.

The Multi-Link approach is to develop a satisfactory approximation to the wholesale customer waiting time solution from a true multi-echelon A_o computation and then use that approximation to build wholesale safety levels on the standard DoD waiting time model and retail levels on retail A_o models. The objective is to realize most of the benefits of multi-echelon A_o modeling while avoiding the difficulties and costs involved in developing and executing a multi-echelon A_o model.

SYSTEM CAPABILITIES

The Multi-Link concept calls for the following three system capabilities:

◆ The capability to identify essential LRUs for a weapon system.

◆ The capability to compute an acceptable approximation for the true multi-echelon solution to the problem of achieving a weapon system A_o target at the least cost or the highest weapon system A_o within a budget constraint.

◆ The capability to apply the response times from the multi-echelon computation into the standard models for the computation of individual item safety levels at the wholesale and retail levels.

ALTERNATIVE MULTI-LINK APPROACHES FOR DERIVING WHOLESALE RESPONSE TIMES

Two alternative approaches exist for providing the second system capability — approximation of true multi-echelon solution. They are referred to as the "1-way-link" and the "2-way-link."[2] Under the 1-way-link approach, the retail A_o is optimized for a range of wholesale response times. The optimal 1-way-link (i.e., the optimal wholesale response time) is at the point at which the sum of wholesale and retail costs has its lowest value. Under the 2-way-link approach, a simplified multi-echelon optimization is performed. The optimal 2-way-link is at the solution of that optimization.

As illustrated in Figure 3-1, the two approaches are embedded in two different automated capabilities currently being developed. The 2-way-link alternative uses a version of the Army Selected Essential Stockage for Availability Method (SESAME) model to develop item wholesale response times. These times are in turn fed into wholesale and retail requirements models, which compute stock levels. The wholesale model will be the safety level computation in the Requirements Determination and Execution System (RD&ES) being developed by the JLSC.
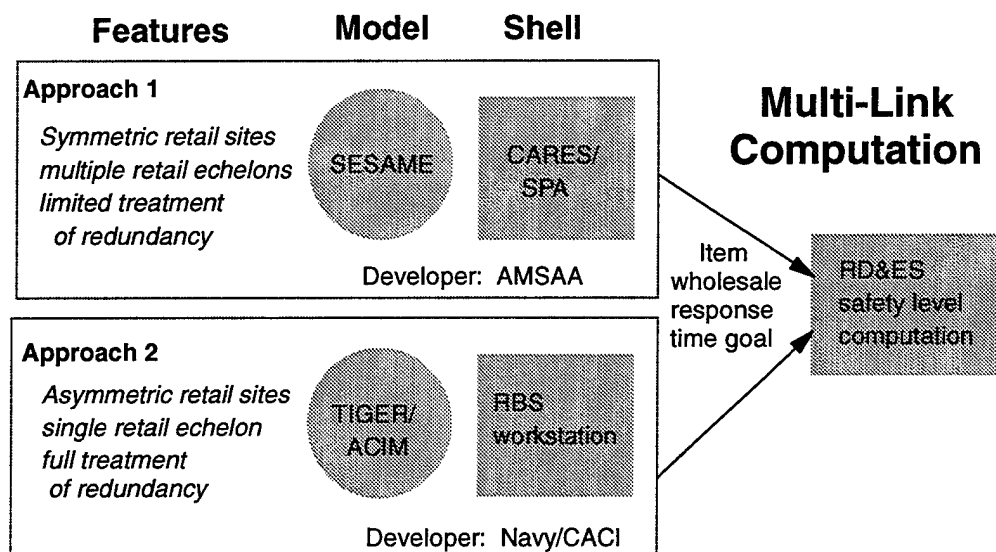
Figure 3-1.
Alternatives for Computing Wholesale Response Time Goals

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[2] In its report, *Evaluation of an Alternative Linkage Strategy* by Tom Hagadorn, the U.S. Army Materiel Systems Analysis Activity (AMSAA) coined the terms 1-way-link and 2-way-link.

The 1-way-link alternative uses a version of the Navy's TIGER/ACIM model to develop wholesale response times from a trade-off of readiness-based retail levels and delay-oriented wholesale levels. Since this procedure computes retail levels, the response times are only entered into the wholesale requirements model. In the following subsections, these approaches are discussed in greater detail.

1-Way-Link and the RBS Workstation

The RBS workstation was initially developed by CACI Inc., a private contractor. The Navy sponsored the initial development of the workstation as a means of computing spares load lists for its ships and aircraft.[3] The load lists are intended to support Navy units and their weapon systems during their periods of deployment. Although the lists constitute retail levels of supply, they are centrally computed at the Navy ICPs. The current version of the workstation is oriented towards the generation of lists for ships and not aircraft, and has been used to generate lists for equipment on the DDG-51 class of guided missile destroyers.

The current workstation uses the 1-way-link approach for setting wholesale and retail requirements. To compute wholesale levels, the workstation uses a personal computer (PC) version of CARES and the combination of TIGER and ACIM to compute retail levels. The procedure is as follows:

◆ The items within a weapon system are grouped by type of item.

◆ Each group is assigned an average depot delay (ADD), which corresponds to a wholesale average customer waiting time.

◆ Using the ADD, wholesale levels are computed.

◆ Using the ADD, retail A_o optimization is performed using ACIM and TIGER.

◆ The total cost of retail and wholesale inventory is computed using the ADD.

◆ The last four steps are repeated until the ADD with the lowest total cost is found.

2-Way-Link and the CARES/SPA Model

The 2-way-link model that is being incorporated in the larger Computation and Research Evaluation System (Navy) (CARES)/Supply Performance Analyzer (Army) (SPA) model[4] is a version of the Army's SESAME model. To differentiate

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[3] The principle lists are the coordinated shipboard allowance list (COSAL) for ships and the aviation consolidated allowance list (AVCAL) for aircraft.

[4] JLSC is developing the CARES/SPA model as an enhanced version of the Navy's CARES model and the Army's SPA model, both of which are used by their respective Services to set wholesale safety level parameters such as performance goals.

it from other versions of SESAME, it is called the Multi-Link model. It is currently under development and has not been applied to a weapon system although the Army has used SESAME for provisioning new weapon systems for more than 15 years.

The proposed 2-way-link procedure would be as follows:

♦ The number of retail sites supporting the weapon system are computed and treated as being equal in demand (i.e., symmetrical).

♦ Multi-Link SESAME is executed in a two-echelon mode, producing item wholesale response time goals.

♦ The item goals are fed into a retail optimization model to compute by site (i.e., symmetrically) retail inventory levels that support demand.

♦ The items are also fed into the wholesale safety level model to compute wholesale levels.

Comparative Analysis

As a basis of comparison, Table 3-1 contrasts the significant characteristics of the 1-way-link and the 2-way-link approaches. Since Multi-Link is still under development, Table 3-1 mixes both how things are done today with how they might work in the future. When the Multi-Link process is finally fielded in its two forms, some of the comparisons may not strictly hold.

To help quantify the differences in results between the 1-way-link approach and the 2-way-link approach, the USAMSAA conducted a number of tests.[5] Summary findings from those tests were as follows:

♦ The 2-way-link spent slightly less total wholesale and retail dollars than the optimal 1-way-link.

♦ The two alternatives differed in their distribution of wholesale and retail dollars.

♦ The 2-way-link had the advantage of a single run to achieve its result, as compared to multiple runs for the 1-way-link.

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[5] Mr. Tom Hagadorn, the principal AMSAA researcher, documented the results of these tests in series of reports entitled *Evaluation of an Alternative Linkage Strategy.*

Table 3-1.

Comparative Characteristics of 1-Way-Link versus 2-Way-Link

Characteristic	1-way-link in RBS workstation	2-way-link in CARES/SPA
Engine	TIGER/ACIM.	SESAME.
Optimization	Currently, retail — marginal analysis within item group wholesale — wholesale Navy and DLA requirements model multi-echelon — tradeoff analysis.	Method of Lagrange multipliers across all items in system across all echelons.
Range of items	Items removed and replaced at the organizational level.	LRUs removed and replaced at the field level.
Demand	For new item, site application demand. For established item, total demand, i.e., new site application demand plus existing demand.	Site application demand.
Commonalty	Weighted average.	AAM approach.
Echelons	Two.	Two.
Form of solution	Wholesale response time goals by item grouping based on factors such as demand, price, etc.	Individual item wholesale response times.
Site treatment	Asymmetric (each ship spared differently).	Symmetric (each site treated the same).
Timing	Once during provisioning and at major changes in weapon system configuration (exact rules governing recomputes not yet established).	During provisioning and periodically for replenishment, either quarterly or annually (exact rules not yet established).
Budget limitations	Must be dealt with manually.	A model parameter.
Executor	Engineering activity or weapon system manager.	Weapon system manager or inventory control point.

Note: RBS = readiness-based sparing; CARES/SPA = Computation and Research Evaluation System (Navy)/Supply Performance Analyzer (Army); TIGER/ACIM = TIGER/Availability Centered Inventory Model; SESAME = Selected Essential Stockage Availability Method.

CHAPTER 4

Applicability of Multi-Link to DLA Weapon System Items

Today, DoD wholesale requirements systems offer the following methods for determining stock levels for a particular type of item:

◆ For consumable items and field-level reparable items, all Components systems currently use single-echelon models targeted at a supply performance goal (either average customer waiting time or supply availability).

◆ For depot-level reparable items, Components except the Air Force, currently use single-echelon models targeted at a supply performance goal.

◆ For depot-level reparable items, the Air Force currently uses a multi-echelon, multi-indenture model that is targeted at A_o or a retail backorder goal.

The future standard system will offer these methods plus the Multi-Link process. The introduction of the Multi-Link process offers the Components an opportunity to choose between two methods for computing requirements for an essential weapon system item. The questions then become, "How are weapon systems and their items selected for the Multi-Link process and who should make these selections?"

WEAPON SYSTEM MANAGER AND ITEM MANAGER

However, before we discuss weapon system and item selection, we need to distinguish between the terms "weapon system manager" and "item manager." Weapon system management and weapon system managers are located within a number of activities within a Service. We limit our discussion to weapon system managers who are charged with providing materiel support to weapon systems.

Service weapon system managers are usually located at a Service ICP and have management responsibility for a set of items in a weapon system. That is, they can be item managers or chief item managers (Army and Navy weapon system managers, respectively). On the other hand, weapon system managers may not be item managers and may not be located at Service ICPs. They can still have full access to the data (e.g., Air Force weapon system managers).

In either case, they do not have full access to data for all of the essential weapon system items. Specifically, they have limited access to DLA data and data from other Services. (For example, Air Force weapon system managers have

access to item data for Air Force-managed reparable items but not DLA-managed consumable items.) In the remainder of this chapter, we use the term "item managers" to refer to those wholesale inventory managers who are not weapon system managers and whose item data are not fully accessible to Service weapon system managers. We use the term "weapon system managers" to refer to those managers who are charged with weapon system materiel support (they may or may not be wholesale item managers but they do have access to wholesale item manager data in their Service).

CANDIDATE SYSTEMS FOR THE MULTI-LINK APPROACH

As the DoD item manager for consumable items, DLA provides materiel support for most, if not all, Service weapon systems. Under DLA's WSSP, the Services identify systems supported by DLA as well as the DLA items in each system. DLA assigns each system a three-character weapon system indicator code (WSIC) and a one-character criticality code that indicates whether the system is most critical (Code A), critical (Code B), and least critical (Code C). The assignment of the criticality code is based on input from the Services.

As a readiness-based sparing technique, the Multi-Link process requires that the weapon system for which it is determining the spares have an A_o goal. It cannot be used for weapon systems that do not have A_o goals. Because of this requirement, not every WSSP system is a candidate for Multi-Link. However, WSSP systems are the logical starting point for Multi-Link candidate systems.

In the following subsections, we review each Service's WSSP systems to assess which might have A_o goals. This review provides a rough idea of the range of systems that might be candidates for the use of the Multi-Link process.

Army Systems

Weapon systems that are normally associated with the Army include helicopters, tanks, armored personnel carriers, artillery, and missile end items. However, the Army also maintains a wide range of tanks, communications, and electronics gear, and engineering end items. Table 4-1 lists general information on Army WSSP systems.

Table 4-1.
Army WSSP Systems

Criticality code	Number	Types of systems
A	20	Helicopters, artillery end items, combat vehicles, missiles, communication systems
B	43	Helicopters, combat vehicles, missiles
C	344	Engineering equipment/vehicles, equipage, landing craft, troop gear
Total	407	

As noted in Chapter 2, the Army has general A_o goals of 75 percent for aircraft and 90 percent for combat equipment and other end items. Those goals would seem to cover helicopters and other aircraft with Codes A and B as well as combat vehicles and artillery end items.

Although tactical communication and other systems with Codes A and B are not weapons and may not fall under the 90 percent goal, the Multi-Link process can be used to determine their spares requirements if they can be repaired at the field level. A_o goals need to be developed for them.

Missiles, which also have Codes A and B, pose a special problem since they only operate when they are fired and, once fired, they can no longer be repaired by removing and replacing failed LRUs. Formulating MTBF for the Multi-Link A_o would be difficult. Furthermore, since missiles have first-indenture items that cannot be removed at the field level, provisions would need to be developed to handle such items.

Many Code C systems may not have A_o goals; whether a system has an A_o goal can be determined from its name. By their title, "systems" that would not have A_o goals would include chemical-biological (CB) masks, the M4 carbine, the M9 multipurpose bayonet, electro-optical bench, etc. However, only the Service equipment manager can confirm whether systems such as air conditioners and telephones have A_o goals.

Navy Systems

Navy weapon systems usually include aircraft, ships, and missile end items. However, as noted in Chapter 2, the Navy views shipboard systems as weapon systems with their own availability goals. Table 4-2 lists general information on Navy WSSP systems.

Table 4-2.
Navy WSSP Systems

Criticality code	Number	Types of systems
A	24	Ships, submarines, aircraft, aircraft engines
B	53	Aircraft, aircraft engines, missiles
C	345	Missiles, shipboard engineering and communications systems and equipment, radars, guns, and personnel support equipment
Total	422	

As noted in Chapter 2, the Navy has A_o goals for aircraft, shipboard systems, and equipment. Those goals would seem to cover most Navy systems except for missiles (i.e., most of the Code A and Code B systems plus many of the Code C systems). Again, missiles may be outside the planned Multi-Link capabilities because of their operating scenario and their maintenance support structure (i.e., site maintenance of missiles is limited since they are munitions).

Some Code C systems may not have A_o goals. Again, the name of a system can help make that determination. Those that are called "systems" and do not have A_o goals include laundry equipment, galley equipment and food service, medical and dental equipment, etc. Only the Service equipment manager can confirm whether or not systems such as deck machinery, reels and towing equipment, eductors, and towed-array handling equipment have A_o goals.

Air Force Systems

Weapon systems normally associated with the Air Force include aircraft and missile end items. However, the Air Force also maintains a wide range of radar and communications systems, aircraft support equipment, and simulators. Table 4-3 lists general information on Air Force WSSP systems.

Table 4-3.
Air Force WSSP Systems

Criticality code	Number	Types of systems
A	25	Aircraft engines, aircraft, helicopters, land and airborne missiles, special programs
B	63	Aircraft engines, aircraft, helicopters, land and airborne missiles, communication and air traffic systems
C	276	Aircraft, simulators, trainer aircraft, support equipment, airborne missiles, aircraft systems, communication and command systems, trucks
Total	364	

Since the Air Force is already using A_o as a basis for determining reparable item support for aircraft, goals for aircraft are readily available. The remaining systems appear to be end items that could have goals. Again, only the Service weapon system manager will be able to confirm this for individual systems.

Marine Corps Systems

Marine Corps aviation weapon systems are considered with those of the Navy. Thus, the nature of the other Marine Corps systems in the WSSP is similar to that of the Army. Table 4-4 lists information on Marine Corps WSSP systems. Like the Army, the Marine Corps has a general A_o goal of 90 percent for its systems. Troop gear, such as night vision goggles, may or may not have this goal.

Table 4-4.
Marine Corps WSSP Systems

Criticality code	Number	Types of systems
A	16	Combat vehicles, communication systems, night vision goggles
B	49	Combat vehicles, artillery, communication systems, missiles
C	144	Artillery, engineering equipment, equipage, trucks, night vision goggles
Total	209	

Who Should Decide on the Use of the Multi-Link Process

The Service weapon system manager is responsible for the performance of an assigned weapon system. Since supply support contributes to weapon system performance, the weapon system manager should be the one to determine how inventory requirements' levels are computed in support of that weapon system. The choices are to compute wholesale stock levels as they are computed today or to compute wholesale stock levels using a Multi-Link approach.

As previously noted, a weapon system must have an A_o goal to be selected for the Multi-Link process. To implement its optimal solution, the Multi-Link process also requires that the retail level supporting the weapon system use an A_o model to build its levels. Since the Services are responsible for setting weapon system A_o goals and for determining what models are used at retail supply activities, they must also be responsible for selecting the weapon systems that should use the Multi-Link sparing process.

Since the AAM is currently used to allocate aircraft reparable spares, can the Multi-Link process be used to allocate consumable items for the same aircraft? Nothing in the Multi-Link procedures would prevent it from being used solely

with consumable items. The MTBF in the Multi-Link A_o formula would have to reflect only consumable item failures. Since the model would be working with consumable items only, Multi-Link A_o targets would have to be adjusted to reflect the absence of the reparable items in the same way the Air Force adjusts the target A_o's that go into the AAM. The one drawback that may exist is that the Air Force is not using retail A_o calculations for consumable items, a prerequisite for the Multi-Link process. (We were not able to test the combination of the current Air Force retail model and Multi-Link wholesale model.)

CANDIDATE ITEMS FOR USE IN THE MULTI-LINK PROCESS

The emerging Multi-Link capability is directed at essential weapon system items that are removed and replaced at the level of maintenance directly supporting a weapon system and that are stocked at the retail supply activity supporting that level of maintenance. For DLA, those items are consumable LRUs. In our 1993 report,[1] we focused on consumable LRUs and their importance to readiness. Not surprisingly, they are also the focus of the Multi-Link process.

How to Identify Multi-Link Items

In our 1993 report, we tied the identification of consumable LRUs to the following item codes:

◆ The source, maintenance, and recoverability (SMR) code.

◆ In the case of the Army, the LRU code.

◆ In the case of the Navy, the weapon system essentiality code.[2]

◆ In the case of the Air Force, the indenture code.

In the Army, consumable LRUs would be items stocked at the level of the unit's prescribed load list (PLL) and possibly the direct support unit (DSU) authorized stock list (ASL); in the Navy, consumable LRUs would be items that are part of a ship's coordinated shipboard allowance list (COSAL) or an air squadron's aviation consolidated allowance list (AVCAL); in the Air Force, they would be items stocked within an air base's standard base supply system (SBSS); and in the Marine Corps, they would be items stocked within a consumer-level of supply and possibly within an intermediate-level of supply tailored towards supporting a specific organization.

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[1] LMI Report DL101R1, *Weapon-System-Oriented Supply Management at DLA: Relating Inventory Investment to Readiness*, Christopher H. Hanks, March 1993.

[2] The Navy has a process for reviewing essentiality codes, and during that process, an item's code may be downgraded for purposes of computing requirements. Like the Navy, DLA should use the revised code and not the starting code.

Additionally, the current plan calls for the use of the Multi-Link process to model LRUs within a two-echelon support structure.[3] As stated in our 1993 report, an LRU is defined as a first-indenture reparable or consumable item that field-level maintenance personnel can remove and replace when it fails.[4] In this case, field-level maintenance is performed by either organizational-level maintenance or intermediate-level maintenance personnel who work directly on operating systems. (That definition excludes both intermediate-level maintenance involved in the repair of items that are removed and replaced at the organizational level and items involved in such repair.) The objective of the Multi-Link process is to determine the optimal set of LRU resupply times among the retail supply activities that are directly supporting the weapon system and the wholesale level supporting those retail supply activities.

An item is a candidate for the Multi-Link process if it is essential to the operation of a weapon system and if all of the time it takes to remove and replace the item when it fails directly affects weapon system downtime. This latter requirement is often associated with items that are removed and replaced at the organizational level of maintenance. Items with an item essentiality code of "1," indicating that ". . . failure of this part shall render the end item inoperable . . ." meet the essentiality requirement. An item's SMR code identifies the level of maintenance at which the item is to be removed and replaced, but the code itself may not be sufficient. It may need to be augmented with an indenture code or an LRU code to determine whether an item meets the impact requirement. The question is, "Who has the data to determine which items meet the criteria?"

Who Should Identify Multi-Link Items

In DLA, item managers have item acquisition and supply data, including an item's essentiality code (as provided to them), but they do not have the SMR, indenture, or LRU codes. Therefore, they would not be in a position to identify candidate items unless they were provided the additional data.

Only Service weapon system managers are in a position to generate the required data. They know their weapon system maintenance plans, how items fit into their systems, and the extent to which items contribute to system operation. With that knowledge, the weapon system manager can identify essential items and those that are removed and replaced at the organizational maintenance level. Service weapon system managers, rather than DLA item managers, are best positioned to decide which items are candidates for the Multi-Link process. They should be able to provide DLA with a list of the DLA-managed LRU's on their

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[3] Although the Multi-Link engine can deal with more than two echelons of supply, the U.S. Army Materiel Systems Analysis Activity concluded that ". . . based on results to date, it is not important to model more than one retail echelon." Details on that analysis are presented in a paper by Mr. Paul Shorter entitled *Comparison of Multi-Link Applications: Two Echelon Computations vs. Three Echelon Computations,* June 1994.

[4] *Weapon-System-Oriented Supply Management* at DLA, op. cit. While the Multi-Link process may be expanded in the future to include more item indenture levels, it will initially focus on LRUs.

weapon systems. Just as important, they should be able to update essentiality and impact coding as changes occur in system configuration and system application and provide those changes to DLA.

From a practical standpoint, another obvious solution to the item identification problem is to include only those items selected for use in the Service retail A_o models. For DLA items particularly, however, that solution begs the question since the Air Force currently is the only Service with a retail A_o calculation in place — and that calculation excludes consumable items.

We have observed several Army and Navy attempts to identify items for A_o modeling. Generally, they identify many DLA-managed items because those items tend to account for a large portion of the failures and tend to cost much less than the Service-managed items. However, many of the items identified simply do not appear to be LRU's. [For example, the Army designates hoses, indicator lights, tubing, etc., as consumable LRUs for our test weapon system although those items are normally associated either with preventive maintenance or opportunity maintenance (maintenance that only occurs when other maintenance is being performed).] We believe that many DLA items are incorrectly identified and, as discussed subsequently, if that incorrectly identified item is included in the optimization with the other items, it can distort the entire stock calculation.

In summary, we believe that the weapon system managers should be responsible for identifying candidate items for Multi-Link computations. We question the adequacy of current methods for identifying consumable item candidates for the Multi-Link process. In the past, however, such identification was not critical to requirements determination. As the Multi-Link process is implemented, the criticality of that identification should increase. Finally, Multi-Link response time goals may be computed for consumable LRUs in some weapon systems and not for the same LRUs in other weapon systems, depending on the decisions of the respective weapon system managers.

DATA PREPARATION

We tested the Multi-Link process with selected Army and Navy weapon systems and present that analysis in Chapter 5. In the following subsections, we discuss the preparation of data on DLA items for the Multi-Link process. Because commonality is important to this discussion, we start with it and then proceed to demand preparation, site treatment, pricing, and cost parameters.

Commonality

Commonality refers to the situation in which an item can be used on more than one end item and/or can be used in more than one way on an end item. In Table 4-5, we show the level of commonality for the DLA-managed LRUs on the Army and Navy systems we tested with the Multi-Link process. To construct Table 4-5, we matched the 1,926 DLA-managed LRU's on these systems to the

DLA WSSP files to determine the number of applications per item. Although almost one-fourth of the items had a single application, almost 60 percent had five or more. That demonstrates the commonality for these items.

Table 4-6.
Commonality of DLA LRUs

Number of applications	Percentage of DLA-managed LRUs	Cumulative percent
1	24.6	24.6
2	9.8	34.4
3	3.9	38.3
4	2.6	40.9
5	2.3	43.2
6 – 10	6.2	49.4
11 – 25	28.8	78.2
> 25	21.8	100.0

Since many of these items are relatively inexpensive, we also looked at commonality as a function of price. Table 4-6 shows the commonality of the 805 DLA-managed LRUs that cost at least $50, about 25 percent of our original 1,926 items. Although we felt that commonality would decrease for these items, we found that not to be the case. Again, the level of commonality remained high, with almost the same percentage of items having five or more applications.

Table 4-5.
Commonality of LRUs with Unit Prices Greater Than or Equal to $50

Number of applications	Percentage of DLA-managed LRUs	Cumulative percent
1	21.9	21.9
2	13.5	34.4
3	4.7	39.1
4	2.5	41.6
5	2.9	43.5
6 – 10	8.3	51.8
11 – 25	41.5	93.3
> 25	6.7	100.0

Of the items in DLA's WSSP, about 58 percent have a single application while about 15 percent have five or more applications. Although those percentages suggest that the consumable LRUs have greater commonality than ordinary

weapon system consumable items, we are reluctant to conclude that since we did not investigate how the Services nominate items for the WSSP. Nevertheless, LRU commonality is significant.

Demand Preparation

Once an item has been identified for Multi-Link requirements determination, the projection of weapon system demand for that item will be a key algorithm in data preparation. Readiness-based sparing works with weapon system demand at the retail level.

1-WAY-LINK APPROACH

The 1-way-link approach deals with new applications and relies on engineering reliability factors and historical data on similar items to estimate an item's retail demand for a new application. Current wholesale demand is used only as a starting point for developing new wholesale demand (i.e., current plus new application).

2-WAY-LINK APPROACH

For consumable items, the 2-way-link approach assumes that weapon system demand at the wholesale level is equal to total retail demand. (For example, an annual wholesale demand of 100 units is assigned a retail demand rate of 100 units per year.) For reparable items, the 2-way-link approach also starts with wholesale demand but must factor in retail repair rates to account for retail demand that is satisfied by local repair. (For example, an annual wholesale demand of 100 units with a retail repair rate of 0.50 is assigned a retail demand rate of 100/.5 or 200 units per year.) Once total retail demand is determined, retail demand at a site is equal to total demand divided by the number of retail sites (under the assumption of symmetric sites as discussed later in this chapter).

However, with one exception, the wholesale demands that DLA and Service ICPs receive from retail supply activities do not specify a weapon system application. The exception is when the requisition is coded to indicate that it is for materiel that will go directly on a weapon system instead of being a normal retail replenishment.

If an item is used only on a single weapon system, all of its demand can be attributed to that application. However, if an item has both a weapon system or multiple weapon system and a non-weapon-system application, the exact portion of its demand that applies to a weapon system is not known.

To overcome that difficulty, the Services relate items to weapon systems and forecast demand for those items based on weapon system program data (e.g., flying hours, end item densities). However, DLA does not use program data to

forecast demand. Moreover, recent LMI analysis has found that demand for DLA items is not highly correlated with weapon system program data.

The DLA can segment demand by Service — and for that matter, by activity — if it uses the DoD activity address code (DoDAAC). However, if an item at an activity has more than one weapon system application and/or another non-weapon-system application, that segmentation does not reduce demand to the weapon system level. In fact, if the demand is for replenishing retail stocks, DLA has no accurate way of knowing, in advance, what portion of that demand will apply to each application, and retail systems do not record demand by application.[5]

For the Army systems, we used failure rates from the Army's Provisioning Master Record (PMR). Although that file starts with an engineering estimate, it may be updated with actual experience. We did find that the data were high in that the projected demand for a DLA item averaged 4.1 times the total recorded DLA demand for that item. We could only suppose that the same was true for Service-managed items and for the system MTBF so that this did not affect the accuracy of our results. For the Navy systems, we used the same demand data currently used in the RBS workstation for those systems.

An AMSAA paper on developing Multi-Link inputs[6] presents a procedure for converting wholesale demand to retail demand for the item on the weapon system. But, in view of the problems with isolating DLA demand for common weapon system items to a specific weapon system, we are not sure that this approach is workable. For items with unique applications or items with one application within a Service, wholesale Service demand can be used as a surrogate for retail demand.

Retail Site Treatment

In using the AAM to determine world-wide requirements, the Air Force is targeting a system-wide A_o goal for each of its general categories of aircraft (e.g., F-16) and treating all aircraft bases as being equal in their aircraft requirements. The term "symmetric" describes that approach. On the other hand, the Navy is interested in computing requirements that reflect A_o goals by type of location (e.g., a deployed ship versus reserve unit), and each location may have different weapon system program requirements. The term "asymmetric" is used to describe this approach.

As originally proposed, the 2-way-link approach would treat retail sites symmetrically. Since the world is asymmetric for all of the Services, an issue arose on whether the symmetric treatment introduces an unacceptable level of

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[5] Local maintenance forms may record piece parts used in repair, but that information is not passed to the local supply system for use in computing levels. Like wholesale systems, retail systems rely on historical demand and planned requirements to build levels.

[6] USAMSAA, Melissa Skubik, *Developing Multi-Link Inputs,* paper, June 1994.

error. AMSAA studied the issue and found, with one exception, that the Multi-Link process loses little in precision in using the symmetric treatment to determine wholesale response time goals (and then using asymmetric computations for actual retail levels). The exception occurs when site-specific A_o targets are needed for low-density weapon systems.[7] That exception would most likely occur in the case of Navy shipboard weapon systems, and the Navy is planning to use the 1-way-link to deal with its systems. Consequently, the Army's analysis appears to have resolved the issue.

Pricing of Materiel

Within the world of DoD logistics, the following multiple unit prices exist for an item:

♦ *The item's acquisition price* — the price the government must pay when it procures the item.

♦ *The item's standard price* — for all items except Air Force reparable items, the price that retail supply must pay when it requisitions the item from the wholesale system and the price the ultimate customer must pay retail supply; for Air Force reparable items when the point of sale is at the base level, the price the customer must pay retail supply.[8]

♦ *An optional reparable item's replacement price* — in some Components, the price a retail supply activity pays for requisitioning a reparable item when it also turns in an unserviceable unit.

The question is which price or prices should be used in the Multi-Link process. The objective of the Multi-Link process is to minimize the inventories that DoD holds to support weapon system readiness. Although it trades off between the wholesale and retail echelons when determining where to position stock, it does not tradeoff between wholesale and retail acquisition (all stocks are purchased at the wholesale level). It takes repair rates and times as given and consequently does not tradeoff between acquiring and repairing stock. In short, it determines how much to buy and where to position it. Therefore, we believe that the Multi-Link process should be using the acquisition price as the cost of an item.

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[7] USAMSAA, Tom Hagadorn, *Multi-Link: A Linked Approach to Multi-Echelon Requirements Determination*, paper, June 1994.

[8] A retail supply activity can procure an item directly from a commercial vendor without requisitioning it from the wholesale supply system. Some such items are designated as local purchase items and are outside the scope of the Multi-Link process, which deals only with centrally managed items. Demand filled by local purchase would not be visible to the wholesaler and therefore would be excluded from Multi-Link computations.

Cost Data

Multi-Link optimization trades off cost against performance. Performance is measured in terms of weapon system A_o, and cost is measured in terms of the wholesale and retail holding costs plus, optionally, retail and wholesale ordering costs. The ordering costs are needed if the model considers order quantities greater than one and allows for the option of not stocking an item.[9]

Although retail holding and ordering costs may be the same for items managed by different ICPs, wholesale holding and ordering costs vary. For example, the General Accounting Office (GAO) reported that holding costs differ by 12 to 23 percent between DoD ICPs. However, within CARES/SPA (the platform for the 2-way-link approach), holding and ordering costs are provided by ICP and therefore would not vary by item manager. Currently, Navy cost parameters are used in the RBS workstation (the platform for the 1-way-link approach). The Navy may change this procedure as the RBS workstation is expanded for greater DoD application.

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[9]With the AAM, the Air Force seeks to minimize the cost of inventory to be procured. Since the Air Force buys an item once a year unless it is in long supply, the number of procurements and the associated costs of ordering are relatively fixed and not a variable in the model. Minimizing the cost of inventory and minimizing the cost of holding, a fraction of the cost of inventory, is the same. Therefore, the real difference between Multi-Link cost minimization and AAM cost minimization is that the Air Force explicitly considers current assets in setting levels, and in doing so, it is minimizing the cost of inventory to be procured versus the cost of on-hand inventory.

CHAPTER 5

Testing and Analysis

To understand how the Multi-Link approach will affect wholesale performance goals, we emulated it on several Army and Navy weapon systems. In particular, we worked with the Multi-Link version of the SESAME model, which represents the 2-way-link approach. The data for each Army system were obtained from the AMSAA in the form of SESAME input files; the data for the Navy systems were obtained from CACI, Inc., in the form of TIGER input files.

We used a two-echelon (wholesale plus one retail) symmetric structure, and assumed all removals occurred at the retail echelon. Retail repair turnaround times and retail-to-wholesale order and shipping times were assumed to be 30 days for all items. The variance-to-mean ratio (VMR) for retail removals was 1.0.

The details of our testing are presented in Appendix A.

TEST FINDINGS

In our testing, we made the following observations:

◆ Item characteristics are such that the Multi-Link process requires extremely high performance at wholesale and retail levels for DLA items, even for moderately large logistics delay time (LDT) targets.

◆ Reallocating the DLA safety level using the current model (DoDI 4140.39) working to the Multi-Link goals results in small cost increases.

◆ Reducing DLA wholesale supply performance shifts inventory to the retail level rather than to non-DLA wholesale inventories.

◆ Constraining the DLA wholesale supply safety level shifts inventory to the retail level.

◆ Constraining non-DLA wholesale supply safety level causes a small increase in wholesale inventory and a small decrease in retail inventory.

INTERPRETATION OF TEST RESULTS

The price and failure characteristics of the input files virtually predict the general nature of the results we obtained.[1] Except for the Q82, DLA items made up, at the minimum, half of all failures. Moreover, the average price of the DLA items was typically less than 5 percent of the average price for non-DLA items. With these conditions, the model will attempt to eliminate backorders for the DLA items because it is cheap to do so and because it produces a big reduction in total backorders.

The Q82 displayed the same relative price characteristics between DLA and non-DLA items as the other systems, but the failures for DLA items were only about 10 percent of the total failures.

LEVELS GENERATION WITH TEST RESULTS

Once the Multi-Link process establishes item goals, the last step is to feed those goals into the current wholesale safety level model to generate stock levels. We replicated this step by taking our test Multi-Link waiting time goals and using them as individual item performance goals in the current DLA safety level model and with current DLA item data. That replication included using the item's current economic order quantity (EOQ), its full demand, its mean absolute deviation of demand, and DLA's current safety level constraints. We found the following:

◆ If unconstrained, the Multi-Link results for dollar investment in safety level would be greater than the current DLA investment in safety level [e.g., the current DLA safety level for the Army's Multiple Launch Rocket System (MLRS) is $146,000; with a five-day MSRT, the Multi-Link level would be $376,000; with a three-day MSRT, it would be $400,000; and with a one-day MSRT, it would be $456,000].

◆ The current safety level constraints would actively influence Multi-Link-based levels (e.g., for the MLRS with one-day MSRT, 6 out of 78 items were constrained by zero safety level minimum with an overall increase of $10,000, while 45 items were constrained by the lead time demand maximum with an overall reduction of $168,000).

◆ After the constraints are imposed, the Multi-Link dollar investment in safety level is still greater than the current DLA investment.

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[1]See Appendix B for the item characteristics.

COMMONALITY AND LEVELS GENERATION

In determining Multi-Link requirements, the following possibilities for an item must be dealt with:

◆ *It may have a single application within an end item* — commonality would not be an issue.

◆ *It may have a single application within multiple end items* — commonality would be an issue.

◆ *It may have multiple applications within an end item* — commonality may or may not be an issue but is resolved by rolling up demand for all applications and then running the model using the roll up.

◆ *It may have multiple applications within multiple end items* — commonality would be an issue.

Commonality is an issue when an item has multiple end-item applications because of the possibility that Multi-Link could compute a different wholesale response time for each application. The question then is, "What is the proper response time goal for the item?"

Unfortunately, our set of test weapon systems did not have common items. Consequently, we were not able to attack the problem of commonality across weapon systems directly. However, within our test Navy systems, item data were available by application. By running each application as a separate item, we arrived at multiple goals for an item. We then considered three different techniques for arriving at a single goal. We looked at a straight average, an average weighted by demand, and the highest goal (i.e., the highest level of support as dictated by the lowest waiting time goal). We found the following:

◆ The safety level dollar differences among the techniques across all items and across the common items were less than 1 percent.

◆ The differences in overall average waiting times were also negligible.

Although this is somewhat an artificial case, it does seem to indicate that a common item does not have a wide range of goals with different applications.

CHAPTER 6

Implementation Issues

Today, Component wholesale managers independently determine their inventory requirements levels. That is, Army managers compute their requirements independent of Navy, Air Force, Marine Corps, and DLA managers who are likewise independent of the Army manager and each other. Moreover, Army, Navy, and DLA inventory control points compute their requirements levels independent of other ICPs in the same Component. The Air Force does the same for the consumable items it manages but depends on the centralized AAM computation for its depot-level reparable items. The Marine Corps has only one ICP. Under the prevailing situation, the requirements determination policy can be set at the DoD level and the concept of operations left to the individual Components.

However, the Multi-Link process crosses Component barriers in that all weapon systems have essential Service-managed reparable items and essential DLA-managed consumable items. Under that situation, the concept of operations cannot be left to the individual Components. Since JLSC is sponsoring the development of the Multi-Link capability, the Services and DLA need to agree on their respective Multi-Link roles, responsibilities, and strategies.

The JLSC must address the following questions:

◆ Who is responsible for determining whether a weapon system or end item is a candidate for using the Multi-Link process? A related question is whether Air Force weapon systems whose reparable item spares are calculated by the AAM are automatic candidates for Multi-Link sparing of their consumable items.

◆ Who is responsible for identifying which items in a weapon system should be subject to the Multi-Link?

◆ Who is responsible for setting A_o goals for end items and ensuring that those goals are acceptable for sparing?

◆ Who is responsible for executing the Multi-Link process?

◆ When, or how often, is the Multi-Link process executed?

◆ What happens when the Multi-Link item wholesale response time goals are not affordable?

In Chapter 4, we addressed the first two questions. In this chapter, we address the last four questions and propose a strategy for DLA. At this time, we are not

in a position to provide a definitive answer to all of the questions that will arise during implementation or, for that matter, to know all of the questions. Our intent is to discuss issues and propose solutions that are supported by logic and where possible, by analysis.

MULTI-LINK PROCESS GOALS

A manager who chooses to compute wholesale stock levels using the current single-echelon, supply-performance method will not be following the DoD guidance that requires that the stock levels of essential weapon system items be computed with an A_o model.[1] However, if the manager chooses the Multi-Link approach, he must be prepared to identify the essential items, assign an achievable weapon system A_o goal, and meet all Multi-Link program data requirements (e.g., number of retail sites).

An option might be to group items and apply different approaches for each group. The Air Force has currently selected that option for its weapon systems when it uses a multi-echelon A_o model for DLR items and a single-echelon, supply-performance model for consumable items. This option, however, is not consistent with current DoD guidance; it incorrectly predicts the effect of item stock levels on weapon system performance, by excluding many conditions that affect performance; and it produces suboptimal results by not trading off costs and benefits across all items.

EXECUTION OF THE MULTI-LINK PROCESS

In this section, we first present a review of some points regarding the execution of the Multi-Link process with DLA consumable items, and then we discuss who should operate the Multi-Link process.

Executing the Multi-Link Process with Consumable Items

In Chapter 4, we noted the difficulty in determining which DLA items are candidates for Multi-Link processing. Those difficulties are magnified by the generation of Multi-Link levels in seeking the low-cost solution to preventing backorders that affect weapon system A_o. Those difficulties only emphasize support for low-cost, high-demand items. Generally, such items are DLA-consumable items. Consequently, the results of our Multi-Link runs for several Army and Navy weapon systems indicated that supply performance goals for

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[1] DoD 4140.1-R, *DoD Materiel Management Regulation*, states the following on page 3-1: "For secondary items that are essential to weapon system performance, the DoD Components shall normally compute requirements with mathematical models that relate range and depth of stock to their effect on the operational availability of the weapon system."

DLA items were very high at both wholesale and retail echelons while the goals for Service-reparable items were lower than normal.

However, the current methods for identifying the population of DLA candidate items appear faulty. Many of the items identified simply do not appear to be LRUs. (For example, the Army designated hoses, indicator lights, tubing, etc., as consumable LRUs for our test weapon system although those items are normally associated either with preventative maintenance or with opportunity maintenance, that is, maintenance that only occurs when other maintenance is being performed.) Overidentification can significantly distort the requirements for the Service LRUs that are included in the optimization with the DLA LRUs. While this issue is complex, what we are primarily concerned with is the use of the Multi-Link process with a specified MTBF. A specified MTBF and A_o target create a unique target for LDT, and the Multi-Link process will convert that target to a target for total retail backorders of LRUs. The more DLA items included, the larger the backorder target and the smaller the stock required. Our observations indicate that the Service items will be the items for which stock is reduced the most. Without knowing the true set of DLA LRUs, we cannot quantify the effect of any execution strategy for using the Multi-Link process with DLA items.

Second, the current formulation of the proposed Multi-Link process assumes one item per weapon system failure. If a consumable item is removed and replaced as part of a maintenance action to remove and replace a failed reparable item, that assumption is incorrect. In addition, if a consumable item is always removed and replaced with other consumable items as part of a maintenance action to fix a particular type of weapon system failure, the assumption would also be invalid. Without knowing the degree of multiple item failures and the different contributions of different consumable items to such failures, we cannot correctly handle DLA items within the Multi-Link.

Third, we learned the following from our Multi-Link process runs and from past SESAME runs that:

◆ The effect of using alternative models (e.g., the current safety level model) to reallocate Multi-Link-determined wholesale safety levels for DLA items are negligible.

◆ Moderate reductions in the targets for DLA items cause an increase in the retail stock for those items, but the overall cost effect is small.

◆ If the retail level uses a days-of-supply model instead of an A_o model, the current wholesale safety level model is preferred to Multi-Link.

Those results seem to indicate that the use of a high aggregate goal in the current safety level model is nearly equivalent to using the Multi-Link process and, in some cases, may be a better solution.

Who Should Execute the Multi-Link Process

In our testing of the Multi-Link process, we targeted on a range of mean supply response times (MSRTs) since we do not know the exact response time that would be required to achieve the A_o target for our test weapon systems. Furthermore, we did not postulate a budget restriction and try to maximize A_o within that restriction.

Weapon system managers know their weapon system A_o goals and could set an overall response time accordingly. Therefore, if they were executing the Multi-Link process, they, unlike us, would be able to target on a response time that produced the desired A_o. However, like us, they would not be concerned with inventory budget restrictions. The result could be item response time goals that might well be shorter than current times and require more budget dollars, particularly if DLA items are included. In summary, since weapon system managers are not concerned with inventory budget restrictions, they could produce item goals that are not affordable to the item managers who must execute within budgets.

If item managers were running the Multi-Link process, they would not be able to target on a response time target since they, like us, would not know the required response time. They would be concerned about budget, but since they are only a small part of the total budget, they would not be in a position to establish a total budget constraint for all of the items in the weapon system.

In summary, we concluded that weapon system managers are in the best position to execute the Multi-Link process. However, if they allow data on consumable and reparable items to be introduced into the Multi-Link process without restriction, the results could be distorted and the goals may not be affordable to DLA.

When the Multi-Link Process Should Be Executed

Level setting is generally done periodically — either monthly or quarterly. It is not done more frequently to avoid unproductive ups and downs in levels; it is not done less frequently to ensure that costs are optimized with relatively current demand, price, and lead-time data. The Multi-Link process does not set wholesale levels per se; rather, it develops A_o-driven targets, which set those levels. Therefore, it does not have to executed as frequently as level setting nor at the same time.

The 1-way-link approach sets targets during initial provisioning. It is envisaged that the targets will remain in place for level setting until a change in end-item configuration or use is sufficient to warrant reprovisioning. Changes in demand and price may move an item to another target group, but they will not change the target for the group. Radical changes in demand would be subject to

an engineering reevaluation rather than a retargeting. In short, the Multi-Link process should be operated on an as-required basis.

LEVELS GENERATION

Once weapon system managers execute the Multi-Link process and produce item response time goals, those goals must be the basis for computing readiness-based wholesale safety levels; that is, response times must be converted to inventory levels. That responsibility should be assigned to DLA item managers since they are in a position to know whether the levels are affordable and within DoD mandatory safety level constraints or whether they need to be reduced. Once the item managers decide on the final levels, the levels must be converted to response times and the times must be retransmitted to weapon system managers for use in computing readiness-based retail levels.

Any reductions in wholesale levels made by item managers will not necessarily subtract from weapon system readiness because the retail RBS model will set retail levels to meet the weapon system A_o goal. That is, it will set higher retail levels to account for the longer response times. In the case of DLA items, we showed that the increased expense should be small compared to the overall retail investment in consumable and reparable item inventory.

We do not mean that DLA can arbitrarily cut support for essential weapon system items because the end result is greater cost to DoD. We do mean that DLA should set affordable goals and perform accordingly so that weapon system managers can depend on stable and expected DLA response times to maintain the integrity of their weapon system performance projections.

OUR RECOMMENDED STRATEGY FOR DLA

On the basis of our analysis, we believe that DLA should participate in weapon system management by giving special attention to items identified as candidate LRUs. However, although the Multi-Link process provides insights into the contribution of these items to weapon system A_o, DLA should not use it to set item wholesale safety levels at this time.

We believe that DLA should take the following actions for weapon systems identified for Multi-Link or AAM application:

◆ Request Service weapon system managers to identify consumable LRUs and make those LRUs the focus of its weapon system support program.

◆ Continue to use the same basic safety level model it now uses for those items, but set the backorder cost to reflect appropriate support for the weapon system. We cannot make specific recommendations on how to set that cost without having more experience in the use of the Multi-Link

process across a wide variety of weapon systems. The promising alternatives are to develop generic weapon system groups and set supply performance goals for the group; or use the backorder costs the Services are using for the specific weapon systems. We recommend that DLA experiment with these two approaches as LRU information is obtained from the Services.

◆ From the resulting safety levels, generate the expected response time performance for individual items. Broadcast that information to allow any retail models to use it in their stock calculations.

Our tests show that following these recommendations will increase wholesale levels for consumable LRUs. Our 1993 report[2] stated, and our test weapon systems revealed, that these items represent a small percentage of the items in the DLA weapon system support program. Our tests show that this will improve DLA support to weapon system A_o.

The above strategy does not impede the Services use of the Multi-Link process. However, the Services might need to set the A_o target to account for additional downtime from consumable LRUs.

If a Service starts to use retail A_o calculations that include DLA-managed items, DLA should be prepared to work with the goals from the Multi-Link process. Again, DLA must feed back the final item response times that it will provide.

DEVELOPMENT OF A MEMORANDUM OF UNDERSTANDING

To ensure that all participants know what is expected of them and what they can expect, a memorandum of understanding should be established among participants when the Multi-Link process is instituted. Precedents for such agreements were established with joint ventures such as the transfer of Service supply depots to DLA. The need for such agreements is obvious in this situation where the success of the requirements determination process depends on the cooperation and proper execution between DLA and each of the Services.

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[2] *Weapon-System-Oriented Supply Management at DLA:, op. cit.* page 2-20.

Details of Testing and Analysis

Details of Testing and Analysis

RESULTS FOR ARMY SYSTEMS

For the wholesale level, we used data recorded by the Selected Essential Stockage for Availability Method (SESAME) to determine the amount of wholesale repair and washouts. All procurement lead times were one year, and all wholesale repair times were 180 days. Wholesale pipeline variance-to-mean ratios (VMRs) were set using the Army Commodity Command Standard System procedure for estimating wholesale pipeline variance. This procedure uses empirically derived tables to estimate demand forecast errors. Wholesale VMRs computed that way are much greater than 1.0.

The following six basic runs were made for each weapon system, and no safety level constraints were applied in any of the runs:

1. The Multi-Link process fully optimized all items [Defense Logistics Agency (DLA) and Service] at both wholesale and retail levels to achieve a logistics delay time (LDT) of five days.

2. The current wholesale model was used to compute DLA wholesale stock levels to the same DLA wholesale safety level dollars that resulted in Run 1. Service items were set using full Multi-Link optimization. The DLA item retail stock level was optimized in coordination with Multi-Link retail backorder costs.

3. This run was the same as Run 2 except the aggregate DLA wholesale backorder delay time from Run 1 was used to set the DLA wholesale stock level.

4. This run was the same as Run 2 except the aggregate DLA wholesale stock availability from Run 1 was used to set the DLA wholesale stock level.

5. This run was the same as Run 2 except the aggregate DLA wholesale stock availability was set at 85 percent.

6. This run was the same as Run 1 except the LDT target was set equal to 10 days.

The purpose of Runs 2, 3, and 4 was to distinguish Multi-Link DLA item performance targets from Multi-Link aggregate DLA wholesale performance targets. Run 5 was conducted to determine the importance of aggregate Multi-Link targets, while Run 6 was conducted to observe the sensitivity of DLA item results to weapon system performance targets.

The summarized results from the six runs are presented in the tables that follow. Each table has three columns of data. The first contains the results for "DLA" items, the second for non-"DLA" items, and the third for all items. DLA is in quotes because all items that had no projected depot maintenance were assigned to DLA along with those currently being managed by DLA. We used no depot maintenance as an indicator of a consumable item that ultimately should be assigned to DLA.

The first row in each table is the LDT, the supply backorder delay at the retail echelon; the second row is the total retail inventory holding cost; the third row is the inventory control point (ICP) backorder delay or wait; the fourth row is the stock availability in units; the fifth row is the ICP inventory holding plus ordering cost; and the sixth row is the total retail and wholesale ICP cost.

Results from the M1A1 Abrams Tank

Table A-1 is the base case for the M1A1 tank and contains the results for the theoretically best solution. Note the extremely high performance demanded from the DLA items. Tables A-2 through A-4 show the results for reallocations of DLA stock from the base case. In all three cases, the impact on total cost is small (less than 0.5 percent) suggesting that aggregate — as opposed to item — performance targets may be adequate for DLA items in a Multi-Link environment. When DLA performance is lowered to 85 percent, as shown in Table A-5, the impact on cost is about 3 percent, which suggests that DLA items should not be removed from the Multi-Link process altogether. Finally, Table A-6 indicates that doubling the LDT to 10 days still results in a solution that demands very high performance from DLA.

Table A-1.
M1A1 Unconstrained Full Optimization
(LDT target = 5 days)

Description	DLA	Non-DLA	All
Logistics delay time	0.08	15.64	5.00
Retail holding cost	$1,331,123.44	$13,000,814.43	$14,331,937.87
ICP backorder wait	2.88	41.12	10.63
ICP stock availability	0.985	0.735	0.934
ICP cost (holding and ordering)	$3,196,355.72	$17,441,573.30	$20,637,929.02
Total cost	$4,527,479.17	$30,442,387.73	$34,969,866.89

Table A-2.

M1A1 Unconstrained Suboptimization
(same DLA cost as full optimization)

Description	DLA	Non-DLA	All
Logistics delay time	0.08	15.66	5.00
Retail holding cost	$1,516,320.36	$13,000,814.43	$14,517,134.79
ICP backorder wait	1.24	41.16	9.34
ICP stock availability	0.994	0.735	0.942
ICP cost (holding and ordering)	$3,196,958.86	$17,409,824.00	$20,606,782.86
Total cost	$4,713,279.23	$30,410,638.43	$35,123,917.65

Table A-3.

M1A1 Unconstrained Suboptimization
(same DLA wait as full optimization)

Description	DLA	Non-DLA	All
Logistics delay time	0.11	15.60	5.00
Retail holding cost	$1,975,736.42	$13,000,814.43	$14,976,550.85
ICP backorder wait	2.88	40.96	10.60
ICP stock availability	0.986	0.736	0.936
ICP cost (holding and ordering)	$2,631,677.81	$17,539,431.76	$20,171,109.57
Total cost	$4,607,414.23	$30,540,246.19	$35,147,660.42

Table A-4.

M1A1 Unconstrained Suboptimization
(same DLA stock availability as full optimization)

Description	DLA	Non-DLA	All
Logistics delay time	0.11	15.60	5.00
Retail holding cost	$2,016,815.26	$13,000,814.43	$15,017,629.69
ICP backorder wait	3.08	40.96	10.76
ICP stock availability	0.985	0.736	0.935
ICP cost (holding and ordering)	$2,591,080.72	$17,539,431.76	$20,130,512.49
Total cost	$4,607,895.99	$30,540,246.19	$35,148,142.18

Table A-5.

M1A1 Unconstrained Suboptimization
(DLA aggregate stock availability = 85 percent)

Description	DLA	Non-DLA	All
Logistics delay time	0.16	15.48	5.00
Retail holding cost	$3,988,757.84	$13,220,079.45	$17,208,837.30
ICP backorder wait	38.26	40.89	38.79
ICP stock availability	0.850	0.736	0.827
ICP cost (holding and ordering)	$1,228,385.03	$17,603,067.38	$18,831,452.41
Total cost	$5,217,142.87	$30,823,146.84	$36,040,289.70

Table A-6.

M1A1 Unconstrained Full Optimization
(LDT target = 10 days)

Description	DLA	Non-DLA	All
Logistics delay time	0.34	30.99	10.02
Retail holding cost	$1,183,336.46	$4,228,912.56	$5,412,249.02
ICP backorder wait		65.83	16.68
ICP stock availability	0.979	0.619	0.906
ICP cost (holding and ordering)	$239,915.74	$6,842,496.82	$9,582,412.56
Total cost	$3,923,252.20	$11,071,409.38	$14,994,661.58

Results for the M2/M3A2 Bradley Fighting Vehicle

Tables A-7 through A-12 contain results for the M2/M3A2. The tables are in the same sequence as those for the M1A1. Results for the M2/M3A2 are similar to the results for the M1A1.

Table A-7.
M2/M3A2 Unconstrained Full Optimization
(LDT target = 5 days)

Description	DLA	Non-DLA	All
Logistics delay time	0.95	24.32	5.01
Retail holding cost	$757,239.90	$1,088,840.36	$1,846,080.26
ICP backorder wait	6.47	68.79	13.06
ICP stock availability	0.978	0.635	0.942
ICP cost (holding and ordering)	$1,280,556.13	$1,446,864.42	$2,727,420.54
Total cost	$2,037,796.02	$2,535,704.78	$4,573,500.81

Table A-8.
M2/M3A2 Unconstrained Suboptimization
(same DLA cost as full optimization)

Description	DLA	Non-DLA	All
Logistics delay time	0.93	24.38	5.00
Retail holding cost	$805,224.27	$1,088,840.36	$1,894,064.63
ICP backorder wait	4.38	69.01	11.22
ICP stock availability	0.986	0.634	0.949
ICP cost (holding and ordering)	$1,280,898.85	$1,439,832.36	$2,720,731.31
Total cost	$2,086,123.22	$2,528,672.72	$4,614,795.94

Table A-9.
M2/M3A2 Unconstrained Suboptimization
(same DLA wait as full optimization)

Description	DLA	Non-DLA	All
Logistics delay time	0.98	24.20	5.01
Retail holding cost	$898,762.21	$1,142,169.32	$2,040,931.54
ICP backorder wait	6.47	70.23	13.22
ICP stock availability	0.979	0.629	0.942
ICP cost (holding and ordering)	$1,167,239.13	$1,406,867.70	$2,574,106.82
Total cost	$2,066,001.34	$2,549,037.02	$4,615,038.36

Table A-10.

M2/M3A2 Unconstrained Suboptimization
(same DLA stock availability as full optimization)

Description	DLA	Non-DLA	All
Logistics delay time	0.98	24.20	5.01
Retail holding cost	$911,107.68	$1,142,169.32	$2,053,277.00
ICP backorder wait	6.74	70.23	13.46
ICP stock availability	0.978	0.629	0.941
ICP cost (holding and ordering)	$1,155,780.01	$1,406,867.70	$2,562,647.71
Total cost	$2,066,887.68	$2,549,037.02	$4,615,924.71

Table A-11.

M2/M3A2 Unconstrained Suboptimization
(DLA aggregate stock availability = 85 percent)

Description	DLA	Non-DLA	All
Logistics delay time	1.02	23.98	5.01
Retail holding cost	$1,530,338.13	$1,142,169.32	$2,672,507.45
ICP backorder wait	45.23	69.19	47.77
ICP stock availability	0.850	0.634	0.827
ICP cost (holding and ordering)	$713,142.25	$1,433,521.76	$2,146,664.01
Total cost	$2,243,480.38	$2,575,691.09	$4,819,171.47

Table A-12.

M2/M3A2 Unconstrained Full Optimization
(LDT target = 10 days)

Description	DLA	Non-DLA	All
Logistics delay time	2.36	46.50	10.02
Retail holding cost	$494,484.47	$303,970.78	$798,455.25
ICP backorder wait	10.55	107.85	20.84
ICP stock availability	0.964	0.466	0.911
ICP cost (holding and ordering)	$1,098,167.75	$736,391.83	$1,834,559.58
Total cost	$1,592,652.22	$1,040,362.61	$2,633,014.83

Results for the Multiple Launch Rocket System

Tables A-13 through A-18 contain results for the Multiple Launch Rocket System (MLRS). Again, the pattern of results is similar to that from the other two systems with the exception that MLRS non-DLA items have higher aggregate supply performance.

Table A-13.
MLRS Unconstrained Full Optimization
(LDT target = 5 days)

Description	DLA	Non-DLA	All
Logistics delay time	0.38	10.88	5.01
Retail holding cost	$359,895.69	$2,921,032.87	$3,280,928.55
ICP backorder wait	5.53	28.61	15.68
ICP stock availability	0.980	0.800	0.901
ICP cost (holding and ordering)	$864,951.50	$2,898,815.15	$3,763,766.65
Total cost	$1,224,847.18	$5,819,848.02	$7,044,695.20

Table A-14.
MLRS Unconstrained Suboptimization
(same DLA cost as full optimization)

Description	DLA	Non-DLA	All
Logistics delay time	0.40	10.88	5.02
Retail holding cost	$372,941.57	$2,921,032.87	$3,293,974.43
ICP backorder wait	3.73	28.61	14.67
ICP stock availability	0.986	0.800	0.904
ICP cost (holding and ordering)	$864,671.38	$2,898,815.15	$3,763,486.53
Total cost	$1,237,612.95	$5,819,848.02	$7,057,460.97

Table A-15.
MLRS Unconstrained Suboptimization
(same DLA wait as full optimization)

Description	DLA	Non-DLA	All
Logistics delay time	0.48	10.75	5.01
Retail holding cost	$433,963.45	$2,929,948.60	$3,363,912.05
ICP backorder wait	5.54	28.51	15.64
ICP stock availability	0.979	0.800	0.900
ICP cost (holding and ordering)	$781,871.77	$2,923,789.42	$3,705,661.19
Total cost	$1,215,835.22	$5,853,738.02	$7,069,573.24

Table A-16.

MLRS Unconstrained Suboptimization
(same DLA stock availability as full optimization)

Description	DLA	Non-DLA	All
Logistics delay time	0.47	10.77	5.01
Retail holding cost	$426,305.03	$2,924,473.03	$3,350,778.05
ICP backorder wait	5.23	28.52	15.47
ICP stock availability	0.980	0.800	0.901
ICP cost (holding and ordering)	$794,081.39	$292,155.84	$3,717,237.23
Total cost	$1,220,386.42	$5,847,628.86	$7,068,015.28

Table A-17.

MLRS Unconstrained Suboptimization
(DLA aggregate stock availability to 85 percent)

Description	DLA	Non-DLA	All
Logistics delay time	0.68	10.53	5.02
Retail holding cost	$940,927.77	$2,929,948.60	$3,870,876.37
ICP backorder wait	47.42	28.06	38.91
ICP stock availability	0.850	0.802	0.829
ICP cost (holding and ordering)	$337,406.78	$2,979,330.12	$3,316,736.90
Total cost	$1,278,334.55	$5,909,278.73	$7,187,613.28

Table A-18.

MLRS Unconstrained Optimization
(LDT = 10 days)

Description	DLA	Non-DLA	All
Logistics delay time	0.81	21.74	10.03
Retail holding cost	$347,373.94	$1,747,683.88	$2,095,057.82
ICP backorder wait	7.52	40.49	22.02
ICP stock availability	0.973	0.734	0.868
ICP cost (holding and ordering)	$774,523.51	$1,858,927.65	$2,633,451.15
Total cost	$1,121,897.44	$3,606,611.53	$4,728,508.97

Results for Constrained Wholesale Safety Levels

Tables A-19 through A-24 present the results of cases for which wholesale reorder points are constrained. There are two tables for each weapon system. In the first table of each pair, wholesale safety level can be no larger than two standard deviations of leadtime demand and the minimum reorder point must achieve at least 50 percent stock availability. In the second table, the above constraints are applied to non-DLA items, and the current DLA constraint is applied to the DLA items, i.e., maximum safety level is the smaller of expected lead time demand or two standard deviations of leadtime demand.

Table A-19.
M1A1 Constrained Optimization (LDT target = 5 days)
Maximum SL < 2 SD; Minimum Reorder Point Achieves
At Least 50 Percent Availability

Description	DLA	Non-DLA	All
Logistics delay time	0.08	15.67	5.01
Retail holding cost	$1,394,106.84	$13,840,282.44	$15,234,389.28
ICP backorder wait	3.48	41.61	11.21
ICP stock availability	0.982	0.746	0.934
ICP cost (holding and ordering)	$3,149,796.70	$17,188,145.85	$20,337,942.55
Total cost	$4,543,903.54	$31,028,428.29	$35,572,331.83

Note: SL = safety level; SD = standard deviation.

Table A-20.
M1A1 Constrained Optimization (LDT target = 5 days)
Maximum SL < 2 SD; Minimum Reorder Point Achieves
50 Percent Availability; Maximum DLA SL < Minimum
(2 SD or Expected Leadtime Demand)

Description	DLA	Non-DLA	All
Logistics delay time	0.09	15.62	5.00
Retail holding cost	$1,694,620.20	$13,849,906.86	$15,544,527.06
ICP backorder wait	6.42	41.32	13.49
ICP stock availability	0.968	0.749	0.924
ICP cost (holding and ordering)	$2,884,125.34	$17,291,693.42	$20,175,818.76
Total cost	$4,578,745.55	$31,141,600.28	$35,720,345.82

Note: SL = safety level; SD = standard deviation.

Table A-21.
M2/M3A2 Constrained Optimization (LDT target = 5 days)
Maximum SL < 2 SD; Minimum Reorder Point Achieves
At Least 50 Percent Availability

Description	DLA	Non-DLA	All
Logistics delay time	0.82	24.94	5.00
Retail holding cost	$865,316.14	$1,414,350.93	$2,279,667.07
ICP backorder wait	7.43	80.99	15.21
ICP stock availability	0.975	0.617	0.937
ICP cost (holding and ordering)	$1,276,389.75	$1,254,135.58	$2,530,525.33
Total cost	$2,141,705.88	$2,668,486.52	$4,810,192.40

Note: SL = safety level; SD = standard deviation.

Table A-22.
M2/M2A2 Constrained Optimization (LDT target = 5 days)
Maximum SL < 2 SD; Minimum Reorder Point Achieves 50 Percent
Availability; Maximum DLA SL < (2 SD or Expected Leadtime Demand)

Description	DLA	Non-DLA	All
Logistics delay time	0.86	24.78	5.01
Retail holding cost	$951,765.07	$1,414,617.33	$2,366,382.41
ICP backorder wait	12.93	80.34	20.06
ICP stock availability	0.956	0.622	0.920
ICP cost (holding and ordering)	$1,191,825.38	$1,272,029.92	$2,463,855.30
Total cost	$2,143,590.45	$2,686,647.26	$4,830,237.71

Note: SL = safety level; SD = standard deviation.

Table A-23.
MLRS Constrained Optimization (LDT target = 5 days)
Maximum SL < 2 SD; Minimum Reorder Point Achieves
At Least 50 Percent Availability

Description	DLA	Non-DLA	All
Logistics delay time	0.39	10.87	5.01
Retail holding cost	$377,197.50	$3,306,116.06	$3,683,313.56
ICP backorder wait	8.66	30.20	18.14
ICP stock availability	0.974	0.803	0.899
ICP cost (holding and ordering)	$850,472.08	$2,570,433.82	$3,420,905.90
Total cost	$1,227,669.57	$5,876,549.88	$7,104,219.46

Note: SL = safety level; SD = standard deviation.

Table A-24.

MLRS Constrained Optimization (LDT target = 5 days)
Maximum SL < 2 SD; Minimum Reorder Point Achieves
50 Percent Availability; Maximum DLA SL < Minimum
(2 SD or Expected Leadtime Demand)

Description	DLA	Non-DLA	All
Logistics delay time	0.43	10.85	5.02
Retail holding cost	$452,858.60	$3,306,116.06	$3,758,974.66
ICP backorder wait	19.72	30.07	24.27
ICP stock availability	0.948	0.804	0.885
ICP cost (holding and ordering)	$786,152.14	$2,577,338.92	$3,363,491.06
Total cost	$1,239,010.74	$5,883,454.98	$7,122,465.72

Note: SL = safety level; SD = standard deviation.

RESULTS FOR NAVY SYSTEMS

Since the Navy is planning to use the 1-way-link and not the 2-way-link, we did not do as extensive a set of runs for the Navy systems as we did for the Army. We wanted only to see if the base case results were different.

The Navy system data were taken from parts files used by CACI, Inc., in the readiness-based sparing (RBS) workstations. Tables A-25 through A-28 show the base case results for four Navy systems: the Close In Weapon System (CIWS), the maneuver control system (MCS), and the C38 and Q82 electronic systems. Only the Q82 displays results much different from the Army systems, i.e., DLA item supply performance goals are on the order of those for non-DLA items.

Table A-25.

Q82 Unconstrained Full Optimization
(LDT target = 5 days)

Description	DLA	Non-DLA	All
Logistics delay time	5.13	4.92	4.98
Retail holding cost	$869,410.70	$2,142,391.77	$3,011,802.47
ICP backorder wait	18.54	12.93	14.42
ICP stock availability	0.925	0.914	0.917
ICP cost (holding and ordering)	$1,500,644.25	$3,019,673.45	$4,520,317.70
Total cost	$2,370,054.95	$5,162,065.21	$7,532,120.16

Table A-26.

C38 Unconstrained Full Optimization
(LDT target = 5 days)

Description	DLA	Non-DLA	All
Logistics delay time	0.52	18.39	4.99
Retail holding cost	$249,915.47	$1,502,190.78	$1,752,106.25
ICP backorder wait	1.84	18.55	6.02
ICP stock availability	0.994	0.863	0.961
ICP cost (holding and ordering)	$705,800.42	$4,864,416.60	$5,570,217.03
Total cost	$955,715.90	$6,366,607.38	$7,322,323.28

Table A-27.

CIWS Unconstrained Full Optimization
(LDT target = 5 days)

Description	DLA	Non-DLA	All
Logistics delay time	0.90	9.57	4.97
Retail holding cost	$1,699,622.17	$5,305,914.21	$7,005,536.38
ICP backorder wait	4.30	12.07	7.95
ICP stock availability	0.991	0.946	0.970
ICP cost (holding and ordering)	$1,327,548.91	$4,124,759.76	$5,452,308.67
Total cost	$3,027,171.07	$9,430,673.97	$12,457,845.05

Table A-28.

MCS Unconstrained Full Optimization
(LDT target = 5 days)

Description	DLA	Non-DLA	All
Logistics delay time	0.36	12.77	5.01
Retail holding cost	$683,960.61	$5,317,650.21	$6,001,610.82
ICP backorder wait	3.46	19.51	9.47
ICP stock availability	0.984	0.840	0.930
ICP cost (holding and ordering)	$1,188,228.52	$9,701,880.72	$10,890,109.24
Total cost	$1,872,189.13	$15,019,530.93	$16,891,720.06

Since all systems but the Q82 wanted high DLA supply performance, we wanted to see the effect that raising the DLA stock availability had on the cost. Table A-29 shows the results for a DLA stock availability equal to 97 percent. For that case, raising the DLA performance results in about a 13 percent increase in total cost.

Table A-29.
Q82 Unconstrained Optimization;
(DLA aggregate stock availability = 97 percent)

Description	DLA	Non-DLA	All
Logistics delay time	3.47	5.41	4.90
Retail holding cost	$652,318.64	$2,061,521.36	$2,713,840.01
ICP backorder wait	6.98	13.51	11.78
ICP stock availability	0.971	0.909	0.925
ICP cost (holding and ordering)	$1,953,420.71	$2,973,733.84	$4,927,154.55
Total cost	$2,605,739.35	$5,035,255.21	$7,640,994.56

Demonstration Weapon Systems

Demonstration Weapon Systems

Tables B-1 through B-7 show the characteristics of the line replaceable units (LRUs) on the weapon systems we used to demonstrate the effect of the Multi-Link process (see Chapter 5). Each table displays, by item category, the number of LRUs, the average price of the LRUs, the percent of total LRU demand, and the percent of total dollar value of LRU demand. The item categories are simply whether the item is or is not managed by DLA. We assigned an item to DLA if it is currently managed by DLA or if it has no requirement for depot overhauling.

Table B-1.
MIAI Tank

Description	DLA	Non-DLA	All
Number of LRUs	205	112	317
Average unit price ($)	404.07	13,020.03	4,861.44
Percent of demand	68	32	100
Percent of dollar demand	2.9	97.1	100

Table B-2.
M2/M3A2

Description	DLA	Non-DLA	All
Number of LRUs	267	52	319
Average unit price ($)	879.74	18,816.05	3,803.53
Percent of demand	82	18	100
Percent of dollar demand	13.5	86.5	100

Table B-3.
MLRS

Description	DLA	Non-DLA	All
Number of LRUs	114	58	172
Average unit price ($)	445.55	8,014.83	2,997.98
Percent of demand	56	41	100
Percent of dollar demand	4.3	95.7	100

Table B-4.

MCS

Description	DLA	Non-DLA	All
Number of LRUs	899	353	1252
Average unit price ($)	189.95	14,707.44	4,283.14
Percent of demand	63	37	100
Percent of dollar demand	2.5	97.5	100

Table B-5.

CIWS

Description	DLA	Non-DLA	All
Number of LRUs	794	295	1089
Average unit price ($)	354.69	10,685.97	3,153.34
Percent of demand	54	46	100
Percent of dollar demand	7.5	92.5	100

Table B-6.

USC38

Description	DLA	Non-DLA	All
Number of LRUs	345	89	434
Average unit price ($)	646.07	13,320.09	3,245.12
Percent of demand	75	25	100
Percent of dollar demand	1.3	98.7	100

Table B-7.

USQ82

Description	DLA	Non-DLA	All
Number of LRUs	235	124	359
Average unit price ($)	654.70	5,111.48	2,194.09
Percent of demand	27	73	100
Percent of dollar demand	25	75	100

The Mathematics of Expressing Operational Availability

The Mathematics of Expressing Operational Availability

Operational availability (A_o) is the DoD measure of the readiness of weapon systems. It is defined as the probability that a weapon system is capable of performing its specified function when called for at a random point in time. In this paper, we examine the mathematics of expressing A_o. Specifically, we review how we calculate A_o, how we formulate A_o estimators for use in readiness-based sparing, how different situations affect the accuracy of these estimators, and finally, how the selection of an estimator affects optimization.

CALCULATING OPERATIONAL READINESS

To quantify A_o, we commonly compare the percentage of time the weapon system is operational, or "up," with the time it is nonoperational, or "down." We calculate that percentage by dividing the total time a weapon system is operational (i.e., up time) by the total time it is available (i.e., total time), which is the sum of its operational and nonoperational time (i.e., up time + downtime).

This calculation can be expressed in several ways:

$$A_o = \frac{UP\ TIME}{TOTAL\ TIME} \qquad \text{[Eq. C-1a]}$$

$$A_o = \frac{UP\ TIME}{UP\ TIME + DOWNTIME} \qquad \text{[Eq. C-1b]}$$

$$A_o = 1 - \frac{DOWNTIME}{TOTAL\ TIME}. \qquad \text{[Eq. C-1c]}$$

A weapon system can be nonoperational for a number of reasons ranging from the failure of an LRU (the focus of the logistics community) to a lack of personnel to operate the system. A more common form of A_o that just considers logistics/failure downtime is given by Equation C-2.

$$A_o = \frac{MTBF}{MTBF + MTTR + MLDT} \qquad \text{[Eq. C-2]}$$

where

MTBF = mean time between failures[1] for a weapon system;

MTTR = mean time to repair the failure when the proper maintenance and supply resources are present; and

MLDT = mean logistics delay time (i.e., the maintenance and supply response times to assemble the proper resources).

For a continuously operating system such as a ground radar system, Equation C-2 may be derived from Equation C-1b, since MTBF is equal to up time and the sum of MTTR and MLDT is equal to downtime. For systems that are not operated continuously such as aircraft, the MTBF term in Equation C-2 must also be multiplied by a factor to account for system idle time, or MTBF must be stated in terms of calendar time rather than operating time (e.g., flying hours).

FORMULATING OPERATIONAL AVAILABILITY ESTIMATORS

Readiness-based sparing is the process of computing item inventory levels that support weapon system availability. In this appendix, we use the term "item" to refer to an LRU and the terms "item inventory level" to refer to the level of spares for an LRU. In order to do readiness-based sparing, we must relate individual item supply performance to weapon system up time. Since the exact calculations of A_o, which are given in Equations C-1 and C-2, do not contain this relationship, A_o models use one of three estimators that do relate inventory levels to weapon system performance.

The First Operational Availability Estimator

The first of the three A_o estimators is founded in Equation C-2; where MTBF is a key variable. Accordingly, we call it the A_o Estimator – MTBF or AEM for short. It is formulated as follows:

$$AEM = \frac{MTBF}{MTBF+MTTR+MSRT},$$ [Eq. C-3a]

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[1]We are using the term "failure" to mean a maintenance action that is also a removal action, that is, a maintenance action where a failed item is removed and replaced thus resulting in a demand on the supply system. This use of the term "failure" excludes maintenance actions that do not include a removal (e.g., a calibration action or a simple tightening of loose screws).

where

MTBF and MTTR are as in Equation C-2, and

MSRT = mean supply response time.

AEM is derived from Equation C-2 by simply limiting logistics delay to the response time for obtaining repair parts to initiate repair (i.e., setting MLDT equal to MSRT). In practice, MTTR is also often omitted because it is small (i.e., from 1/2 to 2 hours), but we left it in the equation for completeness. For intermittent systems, that is, systems not operated continuously, the formula needs to be adjusted for operating tempo (or duty factor). The adjusted formula is as follows:[2]

$$AEM_I = 1 - \left(\frac{DF}{MOTBF}\right)(MTTR + MSRT), \qquad \text{[Eq. C-3b]}$$

where

AEM_I = estimator for intermittent use system,

DF = duty factor or operating tempo, and

MOTBF = mean operating time between failures.

Although MSRT as used in Equation C-2 would be defined as the supply response time associated with a weapon system failure, it is computed for Equation C-3 as a weighted average of item response times:

$$MSRT = \sum_{i=1}^{N} \frac{(Demand_i)(ACWT_i)}{Total\ Demand}, \qquad \text{[Eq. C-4]}$$

where

N = total number of items in the weapon system,

$Demand_i$ = demand for item i,

$ACWT_i$ = average customer waiting time (supply response time) for item i, and

Total Demand = sum of the demand across all N items.

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[2]Source: Frank Strauch of the Navy's operations research office located at Mechanicsburg, Pennsylvania.

This computation assumes one item failure per weapon system failure. As we will see later, that is a key assumption. AEM is used by the Army's Selected Essential Stockade for Availability Method (SESAME)[3] and Navy's Availability Centered Inventory Model (ACIM)[4] A_o models.

The Second Operational Availability Estimator

The second A_o estimator stems from the probability theory, which states that the probability that a number of independent events will occur is the product of the probabilities of each event occurring. Therefore, if the items in a weapon system fail independently, the probability that the weapon system is not down because of a failed item is the product of the individual probabilities that no item failure is causing the weapon system to be down. If N is the total number of "slots" for component i and the spares level for that component results in expected backorders EBO_i, then the probability a random slot is waiting for a spare is EBO_i /N. The probability it is not waiting for a spare is then $1 - EBO_i/N$. More generally, the A_o Estimator — Product or, AEP for short, is given by

$$AEP = \prod_{i=1}^{N} \left(1 - \frac{EBO_i}{QPA_i \times NW}\right)^{QPA_i},$$

[Eq. C-5]

where

EBO_i = expected backorders for item i,

QPA_i = quantity per application of item i on this weapon system, and

NW = total number of weapon systems.

In Equation C-5, AEP is referred to as the product formula and is used by the Air Force Aircraft Availability Model (AAM) A_o model.[5]

The Third Operational Availability Estimator

The third A_o estimator is based on Equation C-1c but, instead of being rooted in weapon system downtime, it works with a fraction of item downtimes. The fraction is called the impact factor and represents the ratio of weapon system downtime to item downtime.

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[3] And SESAME derivatives.

[4] Although the RBS workstation uses ACIM, it estimates weapon system A_o using the Navy's TIGER simulation model.

[5] A variant of the product formula which allows for cannibalization is used in the Air Force's Aircraft Sustainability Model and its Dyna-METRIC assessment model.

For example, an impact factor of 0.20 means that 10 days of item downtime contributes to 2 days of weapon system downtime. A factor of 0.20 would happen if there were an average of five item failures per weapon system failure so that if the five items are concurrently down for 10 days (a total of 50 days of item downtime), the weapon system would be down 10 days. A factor of 1.00 means that, for each day an item is down, the weapon system is down. A factor of 1.00 can only occur if there is one item per failure.

Since the third estimator depends on an impact factor, we call it the A_o Estimator — Impact, or AEI for short. Mathematically, the third estimator is given by

$$AEI = 1 - \sum_{i=1}^{N} (impact\ factor)\left(\frac{EBO_i}{NW}\right).$$ [Eq. C-6]

This form of the estimators does not handle multiple applications of an item within a weapon system (i.e., when $QPA_i > 1$), and it uses a single impact factor although item-oriented impact factor could also be used. The Navy's Aviation Readiness Requirements Oriented to Weapons (ARROWs) model uses this estimator.

Mathematical Relationship Between the Three Estimators

To learn how the three A_o estimators are related, we can express them in terms of a common variable, α, where α equals the sum of item EBOs divided by NW. As developed in detail in Annex 1, AEM becomes

$$AEM = \frac{A_i \times (1-\alpha)}{A_i \times (1-\alpha) + \alpha},$$ [Eq. C-7]

where

$$A_i = \frac{MTBF}{MTBF + MTTR}.$$

A_i is called the inherent availability for a weapon system. As also developed in Annex 1, AEP becomes

$$AEP = e^{-\alpha},$$ [Eq. C-8]

and AEI becomes

$$AEI = 1 - (impact\ factor)(\alpha).$$ [Eq. C-9]

When $\alpha = 0$, all three estimators equal 1.0. When $\alpha = 1$, AEP is 0.37 and AEM is 0 while AEI is one minus the impact factor. Figure C-1 plots the relationships between the estimators assuming there is only one item failure per down weapon system. Under that assumption, the impact factor is 1.0. (We also

included the curve for the impact factor of 0.2 to show the effect of a lower impact factor.)

In Figure C-1, the curve for AEI with an impact factor of one is difficult to distinguish from the AEM curve with A_i equal to 0.95. The AEI is the higher of the two curves where they do not coincide. Observing Figure C-1, we see that AEM consistently yields lower estimates of availability than AEP and AEI. AEP gives higher or lower estimates than AEI depending on the size of the impact factor.
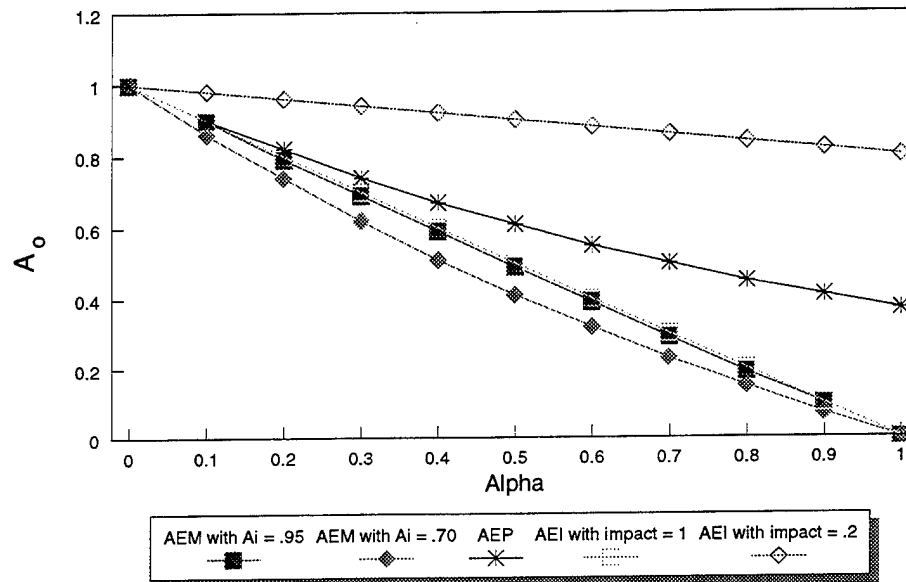
Figure C-1.
Relationship between Estimators

A key driver in establishing the relationships between the estimators is the number of items per weapon system failure. The AEM manifests an inherent assumption that of only one item per weapon system failure. The AEP, on the other hand, assumes that failures are randomly distributed among all weapon system items, and consequently, some probability exists that more than one item failure could occur in a single down weapon system. Since the impact factor is the reciprocal of the average number of items causing the weapon system to be down, the AEI varies depending on that number.

In the following discussion, we test the accuracy of the estimators under different circumstances, including multiple item failures per system failure.

Testing the Accuracy of the Operational Availability Estimators

The three A_o formulas in Equations C-3, C-5, and C-6 are not identical to the A_o formula in Equation C-1, and they rely on certain assumptions. As such, they are merely estimators for the actual A_o. To help us evaluate the accuracy of the A_o estimators, we constructed a simple simulation model. It emulates a hypothetical operating weapon system tracking actual weapon system A_o and comparing it to the values for the three A_o estimators.

The model operates with the following input parameters:

◆ The system MTBF in days (treated as a constant throughout each simulation run of the model).

◆ The number of days being simulated.

◆ The number of items causing a system failure.

◆ The number of items in the weapon system.

◆ The mean time to repair (one day).

◆ The distribution used to assign an item's MSRT.

► *A constant distribution* — all items get the same MSRT.

► *A uniformly increasing distribution* — items are assigned, one at a time, an MSRT starting at a prescribed low value, increasing with a prescribed value, and ending at a prescribed high value and then repeating until all items are assigned (e.g., if prescribed values are "four," "one," and "six," Item 1 gets an MSRT of four, Item 2 gets five, Item 3 gets six, Item 4 gets four, etc.).

► *A bimodal distribution* — a prescribed number of items are assigned the same value and, at a prescribed frequency, the other items are assigned another value (e.g., 9 out of 10 items get the same MSRT of 1 while Item 10 has an MSRT of 41).

The model uses the system MTBF to schedule system failures. For each failure, the model sequentially selects the item or items that cause the failure. For example, if the weapon system consists of four items and each weapon system failure is caused by two items, then the first failure would be caused by Items 1 and 2, the second would be caused by Items 3 and 4, the third by Items 1 and 2, etc. In the model, the weapon system is down until the failed item(s) are removed and replaced, that is, until the item's or items' MTTR and MSRT are

completed. Then the weapon system is up until the next failure, a time interval of MTBF.

The model reports on the following four values (the last three are the estimators):

♦ The actual A_o — Equation C-1

♦ The AEM — Equation C-3

♦ The AEP — Equation C-4 with $QPA_i = 1$ for all i

♦ An AEI — Equation C-5.

To compute the AEI, we used a weapon system population impact factor, that is, the ratio of the weapon system downtime to the sum of the item down times.

With a One-Item Weapon System, How do the Operational Availability Estimators Track Changes in Fixed MTBFs and MSRTs?

To begin our simulation analysis, we started with a one-item weapon system and varied the MTBF and MSRT. The results are shown in Tables C-1 and C-2.

Table C-1 reflects the fact that as the system MTBF increases, system up time is increasing. The result is an increasing A_o. All of the A_o formulas produce the same value and that value corresponds with the actual A_o.

Table C-1.
A_o Analysis: Increasing System MTBF

Case	Number of items	System MTBF	Items per failure	MSRT	Actual A_o (%)	AEM (%)	AEP (%)	AEI (%)
1	1	5	1	5	45.45	45.45	45.45	45.45
2	1	10	1	5	62.50	62.50	62.50	62.50
3	1	25	1	5	80.65	80.65	80.65	80.65
4	1	50	1	5	89.29	89.29	89.29	89.29

Table C-2 reflects the fact that as the item MSRT increases, system downtime is increasing. The result is decreasing A_o. All of the A_o estimators produce the same values and that value corresponds with the actual A_o.

Conclusion: When a weapon system consists of only one item, all A_o estimators accurately track changes in fixed MTBFs and MSRTs.

Table C-2.
A_o Analysis: Increasing System MSRT

Case	Number of items	System MTBF	Items per failure	MSRT	Actual A_o (%)	AEM (%)	AEP (%)	AEI (%)
5	1	25	1	1	92.59	92.59	92.59	92.59
3	1	25	1	5	80.65	80.65	80.65	80.65
6	1	25	1	10	69.45	69.45	69.45	69.45

The Effect on Operational Availability of Increases in the Number of Items in the Weapon System

For our next test, we held all variables constant, except the number of items in the weapon system. The results are shown in Table C-3.

Table C-3.
A_o Analysis: Increasing the Number of Items in the System

Case	Number of items	System MTBF	Items per failure	MSRT	Actual A_o (%)	AEM (%)	AEP (%)	AEI (%)
3	1	25	1	5	80.65	80.65	80.65	80.65
7	2	25	1	5	80.65	80.65	81.58	80.65
8	10	25	1	5	80.65	80.65	82.25	80.65
9	25	25	1	5	80.65	80.65	82.34	80.65
10	100	25	1	5	80.65	80.65	82.39	80.65
11	500	25	1	5	80.65	80.65	82.40	80.65

Since we assigned each item the same MSRT and since the System MTBF was held constant, the increasing number of items had no affect on the actual A_o of the weapon system. However, the A_o based on the product of the individual items availabilities is affected. The AEP formula assumes that items do fail independently but not necessarily separately. Consequently, although we set the number of items per failure to one, the AEP has a number other than one built into its computation.

For example, consider Case 7 in Table C-3. In the simulation, Items 1 and 2 are functioning for 25 units of time; then Item 1 fails and is removed and replaced while Item 2 is still up. Another 25 units of time pass and Item 2 fails. It is removed and replaced while Item 1 is up. Thus, for each item, the probability of being up (U) and the probability of being down (D) are given by

$$U = \frac{25+1+5+25}{25+1+5+25+1+5} = \frac{56}{62}$$

$$D = \frac{1+5}{25+1+5+25+1+5} = \frac{6}{62}.$$

Thus giving us the following:

◆   Probability both items are up = (U)(U) = 3136/3844, or 0.8158.

◆   Probability of Item 1 being down by itself = (D)(U) = 336/3844, or 0.0874.

◆   Probability of Item 2 being down by itself = (U)(D) = 336/3844.

◆   Probability of both items being down = (D)(D) = 36/3844, or 0.0093.

To compute the average number of items down at one time, we only consider instances where one or both items are down. This yields the following:

Items per failure = (336 + 336 + 2*36)/(336 + 336 + 36) = 1.0508.

As the number of items increases, the implied number of items per failure increases. Table C-4 illustrates this for three cases of constant MTBF, MTTR, and MSRT.

Table C-4.
Implied Items per Failures

Number of items	MTBR = 25; MTTR = 1; MSRT = 5	MTBR = 10; MTTR = 1; MSRT = 5	MTBR = 25; MTTR = 1; MSRT = 10
2	1.05	1.1	1.08
10	1.0902	1.1805	1.1453
25	1.096	1.1918	1.1545
50	1.098	1.1955	1.1575
100	1.1	1.2	1.16

When the items per failure are greater than one, weapon system downtime is less than when the items per failure are equal to one. When more than one item fails at a time, the weapon system downtimes associated with each item's failure overlap. In the extreme, if every item failed at the same time, every time,

and every item had the same MTTR and MSRT, then weapon system downtime would simply be the product of the number of failures and the sum of the MTTR and MSRT.

Since the AEP's implied items per failure increases as the number of items increases, the total weapon system downtime decreases. The result is that, if all other system parameters are held constant and the number of items increase, the A_o from the product formula will increase as shown in Table C-3.

[We do not mean that the AEP will always increase as the number of items increase. On the contrary, if item variables are held constant and more items added, the AEP will decrease. (Adding terms to a product when those terms are between zero and one will only decrease the product.) However, in this case, we are *holding system variables constant*, that is, the same number of failures are spread over more items so that each item has fewer failures and its contribution to the product increases as the number of terms increases.]

Since the other two A_o estimators have no built-in assumption on the items per failure, they are not affected by the increase in the number of items.

Conclusion: Only the AEP is affected by the number of items in the system.

With More Than One Item in the Weapon System, How Are The Operational Availability Estimators Affected by Changes in Fixed MTBFs and MSRTs?

We retested Cases 1 through 6 with more than one item in the weapon system. Table C-5 lists the results of this testing.

Table C-5.
Retest of Increasing System MTBF and MSRT

Case	Number of items	System MTBF	Items per failure	MSRT (all items)	Actual A_o (%)	AEM (%)	AEP (%)	AEI (%)
Increasing system MTBF								
12	100	5	1	5	45.45	45.45	57.87	45.45
13	100	10	1	5	62.50	62.50	68.68	62.50
10	100	25	1	5	80.65	80.65	82.25	80.65
14	100	50	1	5	89 29	89.29	89.83	89.29
Increasing MSRT								
15	100	25	1	1	92.59	92.59	92.86	92.59
10	100	25	1	5	80.65	80.65	82.39	80.65
16	100	25	1	10	69 44	69.44	73.64	69.44

Once again, the various A_o's move together with increasing MTBFs and MSRTs. Also, these results support Figure C-1 in that, as the actual A_o gets closer to 100 percent, the A_o estimators get closer together.

Conclusion: With more than one item in the weapon system, all of the A_o estimators correctly respond to changes in fixed MTBFs and MSRTs.

With Only One Item Per Failure, How Are the Operational Availability Estimators Affected by Varying MSRTs?

For our next test, we changed the distribution of item MSRT. Instead of every item getting the same MSRT, we looked at a uniform spread of MSRTs with the same average as the constant MSRT. We considered a narrow spread (i.e., from 4 to 6) and a wide spread (i.e., from 1 to 9). We also looked at a bimodal assignment with which most items get a low value and a few items get a high value; again, the average assignment was the same as the constant MSRT. We considered a small jump (i.e., most items 4 and every 10th item 14) and a large jump (i.e., most items 1 and every 10th item 41). Table C-6 list the results of this test.

Table C-6.
A_o Analysis: Varying MSRTs

Case	Number of items	System MTBF	Items per failure	MSRT (all items)	Actual A_o (%)	AEM (%)	AEP (%)	AEI (%)
Constant MSRT compared to uniform spread								
17	99	25	1	5	80.65	80.65	82.39	80.65
18	99	25	1	4 – 6	80.65	80.65	82.39	80.65
19	99	25	1	1 – 9	80.65	80.65	82.38	80.65
Constant MSRT compared to bimodal spread								
10	100	25	1	5	80.65	80.65	82.39	80.65
20	100	25	1	4, 10, 14	80.65	80.65	82.39	80.65
21	100	25	1	1, 10, 41	80.65	80.65	82.33	80.65

The results show that only the AEP was affected by spreading MSRTs, and the effect was small.

Conclusion: With only one item per failure, varying the MSRTs affects only the AEP, and then the effect is only marginal.

With More Than One Item per Failure, How Well Do the Operational Availability Estimators Track Actual Operational Availability When Item MSRTs Vary?

We next tested varying MSRTs and increasing the number of items per failure. The results are shown in Table C-7.

Table C-7.
A_o *Analysis: Varying MSRTs and Items per Failure*

Case	Number of items	System MTBF	Items per failure	MSRT (all items)	Actual A_o (%)	AEM (%)	AEP (%)	AEI (%)
Constant MSRT and increasing items per failure								
10	100	25	1	5	80.65	80.65	82.39	80.65
22	100	25	2	5	80.65	80.65	67.85	80.65
23	100	25	5	5	80.65	80.65	37.82	80.65
Uniform MSRT spread and increasing items per failure								
19	99	25	1	1 – 9	80.65	80.65	82.38	80.65
24	99	25	2	1 – 9	78.42	80.65	68.75	78.42
25	99	25	5	1 – 9	73.77	80.65	41.07	73.77
Bimodal MSRT spread and increasing items per failure								
21	100	25	1	1, 10, 41	80.65	80.65	82.33	80.65
26	100	25	2	1, 10, 41	71.43	80.65	70.77	71.43
27	100	25	5	1, 10, 41	53.19	80.65	52.27	53.19

Here, for the first time, we find that AEM does not track with the actual A_o. To illustrate why, let us consider the first two failures in Case 27. As shown in Figure C-2, nothing fails for the first 25 days. Then, a failure occurs with 5 items contributing to the failure. They all have an MTTR of 1 and an MSRT of 1, so the weapon system is down 2 days. The next 25 days, the weapon system is again up. Then, the second failure occurs with the next 5 items contributing to the failure. Items 6 through 9 all have an MTTR of 1 and an MSRT of 1, but Item 10 has an MTTR of 1 and an MSRT of 41. The weapon system is down until all failed items are removed and replaced.

The AEM looks at the item MSRTs and averages them to get an average MSRT of 5. The resulting A_o is the same as when all items had 5 days as their MSRT. This formula does not take into account the fact that, for the second failure, Item 10 drives weapon system downtime. The down times for Items 6 through 9 are incidental unless they get to be larger than the MSRT for Item 10. So, in this case where multiple items contribute to a failure with a widespread of

MSRTs, the AEM no longer tracks with the actual A_o. (This is expected since a key assumption in using this formula is that only one item causes a failure.)
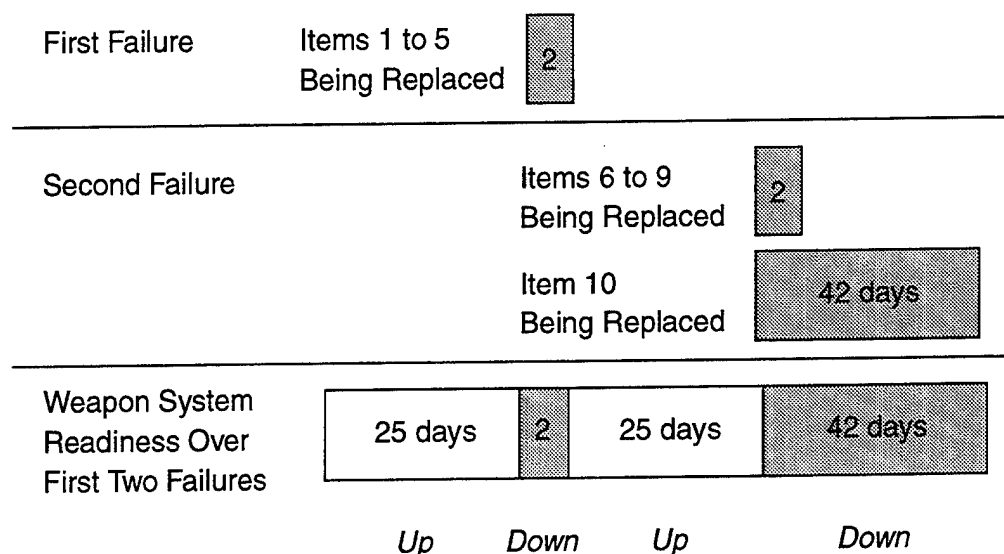
Figure C-2.
Item Failures and Weapon System Readiness

On the other hand, the AEP does a better job with this situation. To understand why, let's compute the AEP for the first two failures, or 94 days of operating the weapon system. Items 1 through 9 would be functioning 92 out of 94 days, or 97.9 percent of the time, while Item 10 is only working 52 days, or 55.32 percent of the time. All other items are operating 100 percent of the time. The product of the percentages is 45.58 percent. It is driven by Item 10 with the lowest percentage. We conclude from this test that in cases in which significant spread occurs between overlapping item downtimes, the AEP outperforms the AEM since it is concerned with the spread of MSRTs and not merely the average MSRT.

However, although the mathematical structure of the AEP provides a better estimate in this case, this is not the same as mathematical equivalence. In Case 25, item downtimes vary and they overlap, but the AEM is still a better estimator.

Conclusion: For weapon systems for which there is only one item per failure, that is, where total item downtime and weapon system downtime are approximately the same, the AEM formula is a good estimator of actual A_o. In cases in which there is more than one item per failure, that is, where total item downtime is significantly greater that weapon system downtime, the AEM formula may or may not be the better estimator.

Why Does Our Test AEI Mirror Actual Operational Availability?

For all of our test results, the AEI was always equal to the actual A_o as a direct consequence of how we computed our impact factor (f). That computation was

$$f = \frac{DOWNTIME}{\sum (Downtime_i)} \qquad \text{[Eq. C-10]}$$

where

DOWNTIME = weapon system downtime, and

$Downtime_i$ = the downtime for Item i.

If we divide the quotient of total item downtime and total time available by the days in a year, we have the following:

$$\frac{\sum (Downtime_i)}{TOTAL\ TIME} = \frac{\sum (EBO_i)}{NW} = \alpha,$$

or

$$\frac{1}{\sum (Downtime_i)} = \frac{1}{(TOTAL\ TIME)(\alpha)}.$$

If we substitute this expression in Equation C-10, we would get the following equation for an impact factor:

$$f = \frac{DOWNTIME}{(TOTAL\ TIME)(\alpha)} \qquad \text{[Eq. C-11]}$$

Now, if we substitute Equation C-11 into Equation C-9, we would have Equation C-1c, the actual A_o formula. Therefore, the two A_os are equivalent to each other with the impact factor that we used. Our test results only confirmed that mathematical equivalence.

However, our test results also showed that, with the right impact factor, the AEI can accurately track actual A_o. The problem is to get the right factor. We used weapon system downtime over the sum of item down times. However, item down times are directly related to levels of inventory. More inventory means lower item downtime and this, in turn, changes the value of the impact factor.

The actual impact factor for weapon system is a function of its configuration, its A_o goal, and its readiness-based levels of supporting inventory. One estimate of the proper impact factor would be the weapon system's current factor. If the weapon system program is fairly stable and the A_o model used to compute its supporting levels is fairly correct, the factor should have a small error.

Since we can only estimate the impact factor in a real situation, the question is how sensitive are AEI estimates to errors in estimating an impact factor. As illustrated in Table C-8, it depends on the situation.

Table C-8.
Error in Estimating A_o Caused by an Error in Setting the Impact Factor

Error in setting impact factor (%)	Case 25; actual test factor = .2963 (%)	Case 27; actual test factor = .7333 (%)
− 50	18	44
− 20	7	18
− 10	4	9
− 5	2	4
5	− 2	− 4
10	− 4	− 9
20	− 7	− 18
50	− 18	Not applicable

[a] Since factor must be less than or equal to one.

Comparing these results to the results in Table C-7, we can see that, if we had a 20 percent error in setting our impact factor in Case 25, the AEI would still outperform the AEM and the AEP. However, in Case 27, we would need an error of less than 5 percent for the AEI to outperform the AEP. These two cases would imply that the use of the AEI should be limited to cases where overlapping down times for items are not widely spread apart.

Conclusion: The AEI is a good estimator of actual A_o if the error in setting an impact factor is small or the actual impact factor is small (i.e., considerable overlapping of item failures).

HOW THE OPERATIONAL AVAILABILITY ESTIMATORS AFFECT OPTIMIZATION

From our previous analysis, we know that the A_o estimators will not produce the same stockage lists in all cases because, during optimization, they will cut off at different points, depending on when they estimate that they have reached the targeted A_o. It can be argued that this problem is not important since the estimators can be calibrated to cut off at the same point. In response, we would question the ease and accuracy in calibrating A_o estimators either to the actual A_o or to the other estimators. However, even if the calibration could be

done but the A_o estimators do not select spares in the same order, they would still not produce the same stockage lists.

To explore the question of whether the A_o estimators select spares in the same order, we use marginal analysis as our method of optimization. That is, we develop a cost-benefit ratio for buying a spare for each item and select the spare with the lowest ratio. In that way, we can determine the order that the estimators are selecting spares. The basic form of the ratio is as follows:

$$Ratio = \frac{Cost\ of\ Spare}{A_o\ with\ spare - A_o\ without\ spare}. \qquad \text{[Eq. C-12]}$$

In developing a ratio for a spare for Item i, the cost of the spare is the cost of Item i (C_i) while the A_o's with and without a spare depend on which A_o estimator is being used. To help us investigate how each A_o estimator performs, let us define $EBO_j(s_j)$ as the expected backorders for Item j when Item j has an inventory level of s_j. Then, the variable $EBO_j(s_j - 1)$ would represent the expected backorders with one less spare.

The Operational Availability Difference for Each Estimator

As shown in Annex 2, the difference between the AEMs with and without a spare depends on the difference between MSRT with the spare and MSRT without the spare, since MTBF and MTTR are not affected by the level of sparing for an item (i.e., they are constant). Accordingly, for purposes of this analysis, we define the difference in AEM estimates (ΔAEM) as the difference in MSRT ($\Delta MSRT$) and write that definition as follows:

$$\Delta AEM = (k)[EBO(s_{j-1}) - EBO(s_j)], \qquad \text{[Eq. C-13]}$$

where

k = 365 divided by the total demand across all N items.

For AEP and AEI, the A_o differences are direct and, as shown in Annex 2, are given by

$$\Delta AEP = \frac{1}{NW}[EBO(s_j - 1) - EBO(s_j)] \prod_{i=1,\, i \neq j}^{N} \left(1 - \frac{EBO_i}{NW}\right), \qquad \text{[Eq. C-14]}$$

and

$$\Delta AEI = (f)[EBO(s_j - 1) - EBO(s_j)], \qquad \text{[Eq. C-15]}$$

where

f = weapon system impact factor and

NW = number of weapon systems.

Although the Air Force's AAM uses AEP for its marginal analysis, its "bang for the buck"[6] is computed as follows:

$$\Delta AAM = \ln\left(\frac{1 - \frac{EBO(s_j)}{NW}}{1 - \frac{EBO(s_j - 1)}{NW}}\right) / cost.$$

[Eq. C-16]

Testing the Difference

To evaluate the different equations, we constructed a simple example. It involves a weapon system with three items, all having the same price (therefore, price is not an issue in selecting a spare). Table C-9 shows the data involved in the optimization. We assumed that the number of weapon systems is 20 and the system impact factor is 0.5.

Table C-9.
Operational Availability Estimators and Optimization

Item	1	2	3
Annual demand	10	10	10
EBOs without spare	10	4.2	4
EBOs with spare	8.2	2.2	3
Difference	1.8	2	1
ΔAEM	13.967	14.167	13.167
ΔAEI	2.3	2.5	1.5
One – EBO/NW without spare	0.5	0.79	0.8
One – EBO/NW with spare	0.59	0.89	0.85
Product of one – EBO/NW less Item	0.632	0.4	0.395
ΔAEP	0.057	0.04	0.02
ΔAAM	0.17	0.12	0.06

Table C-9 shows that the selection for AEM and AEI is Item 2 while the selection for AEP (using either the actual or AAM difference) is Item 1.

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[6] LMI Report AF201. *The Aircraft Availability Model: Conceptual Framework and Mathematics*, T. J. O'Malley, June 1983, p. C-8.

The fact that AEM and AEI make the identical selection only confirms the mathematics in Equations C-13 and C-15 that shows that they only differ by a constant. Thus, they should always select spares in the same order.

On the other hand, this example also proves that a case can exist in which the AEP estimator will select a different spare. Of course, we could construct many examples in which all three estimators select spares in the same order. Moreover, the same set of spares could be selected for a given A_o or dollar target even though they are not selected in the same order because EBOs are the key terms in all three estimators. However, as the example shows, we cannot say that all three estimators will always select the same spares in the same order.

Conclusion: For a given A_o target, the three estimators will compute different inventory levels because of (1) differences in when they cut off sparing, and (2) in some cases, differences in the order in which they select spares, although the associated differences in levels should be minor.

Summary of Analysis

This analysis shows the following:

◆ Readiness-based sparing requires the use of A_o estimators that relate weapon system performance to item inventory levels.

◆ Existing A_o models use one of three primary A_o estimators.

◆ Each of the three potential estimators of A_o have applications in which they are more accurate in portraying the actual A_o than the other estimators. No one estimator is clearly superior to the others in all cases.

◆ The estimator planned for use in Multi-Link process (i.e., AEM) overstates the effectiveness of spares in increasing A_o when weapon system failures are characterized by multiple simultaneous item failures.

◆ The three estimators will not always produce the same levels of inventory to support a performance goal for a weapon system.

Based on this analysis, we recommend that the Multi-Link process capability provide for all three estimators to allow weapon system managers to tailor their readiness-based sparing to their systems.

Redefining the A_o Estimators in Terms of a Common Variable

Redefining The A_o Estimators in Terms of a Common Variable

IMPORTANT AND COMMON QUANTITY IS EBO/END ITEMS

This annex demonstrates how the A_o estimators, AEM, AEP, and AEI can be expressed in terms of a common variable. For reference, AEM is given by

$$AEM = \frac{MTBF}{MTBF+MTTR+MSRT}.$$ [Eq. C-1-1]

AEP is given by

$$AEP = \prod_{i=1}^{N} \left(1 - \frac{EBO_i}{QPA_i \times NW}\right)^{QPA_i},$$ [Eq. C-1-2]

and AEI is given by

$$AEI = 1 - (impact\ factor) \sum_{i=1}^{N} \left(\frac{EBO_i}{NW}\right).$$ [Eq. C-1-3]

In the discussion that follows, the sum of EBOs (SEBO) for all items in the weapon system (N) is given by

$$SEBO = \sum_{i=1}^{N} (EBO_i),$$

and the constant alpha (α) is defined as

$$\alpha = \frac{SEBO}{NW}.$$ [Eq. C-1-4]

REDEFINING AEM

With a few substitutions, Equation C-1-1 can be written in terms of α and the inherent availability of the weapon system (A_i), which we define later. Two of the key substitution equations (Equations C-1-5b and C-1-6) are listed in what follows. Equations C-1-5a and C-1-5b are two versions of a relationship among demands, mean time between failures, the number of total weapon systems, and the number of available weapon systems. Equation C-1-5b is correct; Equation C-1-5a is provided to assist in building a case for Equation C-1-5b.

At first glance, Equation C-1-5a could appear are to be correct. One might say that the total failures per day *per weapon system* is equal to the reciprocal of the mean time between failures (MTBF in days) *per weapon system*. Thus, if we have an average of 10 item failures per day across N items (the numerator of the left side of Equation C-1-5a) that are being generated by a total of 50 weapon systems (NW), then the average number of failures per day is 0.2 *per weapon system* (10/50) and the MTBF on a weapon system is 5 days.

$$\frac{\sum_{i=1}^{N} DDR_i}{NW} = \frac{1}{MTBF},$$ [Eq. C-1-5a]

where

DDR_i = the daily demand rate for item i.

Equation C-1-5a is not totally correct because it fails to consider the fact that only operating or "up" systems have failures while systems that are down do not generate demand. Thus, since the average number of "up" systems is less than the total number of system, the total daily demands should be divided by this lower number of weapon systems to attain the reciprocal of MTBF.

For example, if an average of 40 out of 50 systems are up with demands totaling 10, then the system MTBF would be four days instead of the five days we previously computed. To verify this, you need only start with an MTBF of four days and an assumption that the total delay (MTTR + MLDT) is one day. This would yield an 80 percent availability (40 out of 50 systems "up") and an average number of 10 failures per day. Thus, Equation C-1-5b provides the correct relationship between the variables MTBF and DDR_i by introducing the variables NW and A_o.[1]

$$\frac{\sum_{i=1}^{N} DDR_i}{NW \times A_o} = \frac{1}{MTBF}.$$ [Eq. C-1-5b]

Little's formula says that the total expected number of steady-state backorders (i.e., SEBO) is equal to the total number of failures times the average supply delay in providing a spare part. This is shown in Equation C-1-6. Thus, if we had 10 demands (item failures) per day and an average response time of 2 days for each demand, then the expected number of backorders would be 20. One way this could occur is if the supply availability were 90 percent and the average backorder time was 20 days whenever we were out of stock. The MSRT across all items would be 2 days (.9 x 0 + .1 x 20). In this case, 10 percent of the daily

---

[1] In Equations C-1-5a and C-1-5b, we are assuming that the number of items per failure is one. If the number of items per failure (N) is greater than one, then N must be included as the nominator of the right hand side of each equation or as part of the denominator of the left hand side of each equation.

demands (1 per day) would be backordered for 20 days giving a total of 20 back-orders in the steady state.

$$\left(\sum_{i=1}^{N} DDR_i \right) \times MSRT = \sum_{i=1}^{N} EBO_i = SEBO. \qquad \text{[Eq. C-1-6]}$$

Combining Equations C-1-5b and C-1-6 gives the following for MSRT/MTBF:

$$\frac{MSRT}{MTBF} = \frac{SEBO}{NW \times A_o} = \frac{\alpha}{A_o}. \qquad \text{[Eq. C-1-7]}$$

If we divide the top and bottom of Equation C-1-1 by MTBF and then substitute Equation C-1-7 into Equation C-1-1 we get:

$$AEM = \frac{1}{1 + \frac{MTTR}{MTBF} + \frac{\alpha}{A_o}}. \qquad \text{[Eq. C-1-8]}$$

If we assume no maintenance delay in MLDT (i.e., MLDT = MSRT), then the following relationship between A_o and AEM falls out of Equations C-1-2 and C-1-3 in the main text:

$$\frac{1}{A_o} = \frac{1}{AEM}. \qquad \text{[Eq. C-1-9]}$$

Substituting Equation C-1-9 into Equation C-1-8 and solving for AEM gives Equation C-1-10.

$$AEM = \frac{1 - \alpha}{1 + (\alpha) \times \left(\frac{MTTR}{MTBF} \right)}. \qquad \text{[Eq. C-1-10]}$$

Equation C-1-10 can now be rewritten in terms of the inherent availability (A_i), which is defined as the availability when there is no logistics delay.

$$A_i = \frac{MTBF}{MTBF + MTTR}. \qquad \text{[Eq. C-1-11]}$$

From Equation C-1-11, we find that $\left(\frac{MTTR}{MTBF} \right)$ is equal to $\left(\frac{1}{A_i} - 1 \right)$. With this substitution, Equation C-1-11 becomes

$$AEM = \frac{A_i \times (1 - \alpha)}{A_i \times (1 - \alpha) + \alpha}. \qquad \text{[Eq. C-1-12]}$$

REDEFINING AEP

It can be shown[2] that in most applications of Equation C-1-2, $\left(1 - \frac{EBO_i}{QPA_i \times NW}\right)^{QPA_i}$ is closely approximated by $e^{\left(\frac{-EBO_i}{NW}\right)}$. With this substitution, Equation C-1-2 can be rewritten as Equation C-1-13 as follows:

$$AEP = e^{\left(-\frac{SEBO}{NW}\right)} = e^{-\alpha}. \qquad \text{[Eq. C-1-13]}$$

REDEFINING AEI

With the two simple substitutions noted in the front of this annex, Equation C-1-3 for AEI can be rewritten as follows in terms of α:

$$AEI = 1 - (impact\ factor)\frac{SEBO}{NW} = 1 - (impact\ factor)\,\alpha. \qquad \text{[Eq. C-1-14]}$$

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[2] O'Malley, pp. A-1 and A-2.

Defining the Impact of Operational Availability of Adding a Spare Using the Operational Availability Estimators

Defining the Impact on Operational Availability of Adding a Spare Using the Operational Availability Estimators

This annex defines the difference between the A_o with a spare and the A_o without the spare when A_o is estimated using AEM, AEP, and AEI.

USING AEM

We know from Little's formula on queuing that

$$ACWT_i = \frac{EBO_i}{DDR_i} = \frac{(EBO_i)(365)}{Demand_i},$$ [Eq. C-2-1]

where

DDR$_i$ = the daily demand rate for item i.

Substituting Equation C-2-1 into Equation C-4 of the main text of this appendix yields

$$MSRT = k \sum_{i=1}^{N} (EBO_i),$$ [Eq. C-2-2]

where

k = 365 divided by the total demand across all N items.

Thus, the difference (Δ) between the MSRT with a spare for Item j and the MSRT without a spare is as follows:

$$\Delta MSRT = (k)[EBO(s_{j-1}) - EBO(s_j)].$$ [Eq. C-2-3]

What remains to be shown is that if the largest MSRT decrease occurs when adding a spare for some Item j versus a spare for any other Item i, i.e., $\Delta MSRT(s_j) \geq \Delta MSRT(s_i)$, then the same spare will cause the largest AEM increase, i.e., $\Delta AEM(s_j) \geq \Delta AEM(s_i)$.

If $\Delta MSRT(s_j) \geq \Delta MSRT(s_i)$, then we have

$$MSRT(s_j - 1) - MSRT(s_j) \geq MSRT(s_i - 1) - MSRT(s_i).$$

But the MSRT before adding a spare for item j is the same as the MSRT before adding a spare for any other Item i, i.e., $MSRT(s_j - 1) = MSRT(s_{io} - 1)$. Therefore, we have

$$-MSRT(s_j) \geq -MSRT(s_i) \text{ or } MSRT(s_j) \leq MSRT(s_i).$$

Adding the constants MTBF and MTTR to both sides of the inequality yields

$$MTBF + MTTR + MSRT(s_i) \geq MTBF + MTTR + MSRT(s_j).$$

Cross-multiplying and multiplying both sides of the inequality by MTBF yields

$$\frac{MTBF}{MTBF + MTTR + MSRT(s_j)} \geq \frac{MTBF}{MTBF + MTTR + MSRT(s_i)}.$$

By definition, that is equivalent to

$$AEM(s_j) \geq AEM(s_i).$$

Since the A_o estimate before adding a spare for item j is the same as the A_o estimate before adding a spare for any item i, i.e., $AEM(s_j - 1) = AEM(s_i - 1)$, we can subtract it from both sides of inequality:

$$AEM(s_j) - AEM(s_j - 1) \geq AEM(s_i) - AEM(s_i - 1),$$

or by definition

$$\Delta AEM(s_j) \geq \Delta AEM(s_i).$$

By reversing the steps, we could show that the spare that yields the greatest increase in the AEM also is the spare that yields the greatest decrease in MSRT. Thus, we have shown that optimizing on MSRT is equivalent to optimizing on AEM (i.e., focusing on the MSRT impact in selecting spares will yield the same result as focusing on the AEM impact).

In this formulation, the change in availability rate resulting from an additional spare of Component j, depends on the support provided by the other components; thus the problem looks nonseparable and nonamendable to marginal analysis optimization. However, the *ratio* of the availabilities is independent of the other components.

$$= \left[1 - \frac{EBO(s_j)}{NW} \right] \prod_{i \neq j}^{N} \left(1 - \frac{EBO_i}{NW} \right)$$

$$\frac{AEP(s_j)}{AEP(s_j - 1)} = \left[1 - \frac{EBO(s_j - 1)}{NW} \right] \prod_{i \neq j}^{N} \left(1 - \frac{EBO_i}{NW} \right)$$

$$= \frac{\left[1 - \frac{EBO(s_j)}{NW} \right]}{\left[1 - \frac{EBO(s_j - 1)}{NW} \right]}.$$

The Aircraft Availability Model exploits this "product reparability" by using marginal analysis to maximize ln(AEP) subject to cost. Taking the logarithm transforms the multiplicative domain to the additive domain, and, of course, maximizing the logarithm is equivalent to maximizing the availability.[1]

USING THE AEP

To simplify the mathematical development that follows, we'll assume that QPA_i equals one for all items. If $AEP(s_j - 1)$ is the A_o estimate before a spare is added for any item j and $AEP(s_j)$ is the estimate after the spare is added, we have the following:

$$AEP(s_j - 1) = \prod_{i=1}^{N} \left(1 - \frac{EBO_i}{NW} \right) = \left(1 - \frac{EBO_j(s_j - 1)}{NW} \right) \prod_{i=1, i \neq j}^{N} \left(1 - \frac{EBO_i}{NW} \right),$$

and

$$AEP(s_j) = \left(1 - \frac{EBO_j(s_j)}{NW} \right) \prod_{i=1, i \neq j}^{N} \left(1 - \frac{EBO_i}{NW} \right).$$

Hence, the difference between the two AEPs is given by

$$\Delta AEM(s_j) = \left[\left(1 - \frac{EBO_j(s_j)}{NW} \right) - \left(1 - \frac{EBO_j(s_j - 1)}{NW} \right) \right] \prod_{i=1, i \neq j}^{N} \left(1 - \frac{EBO_i}{NW} \right),$$

This simplifies to

$$\Delta AEP = \frac{1}{NW} [EBO(s_j - 1) - EBO(s_j)] \prod_{i=1, i \neq j}^{N} \left(1 - \frac{EBO_i}{NW} \right).$$

Note that, if QPA_i is not equal to one for all items, then we have

$$\Delta AEP = \frac{[EBO(s_j - 1) - EBO(s_j)]^{QPA_j}}{NW(QPA_j)} \prod_{i=1, i \neq j}^{N} \left(1 - \frac{EBO_i}{(NW)(QPA_i)} \right)^{QPA_i}.$$

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[1]O'Malley, Chapter 3 and Appendix C.

USING AEI

If $AEI(s_j - 1)$ is the A_o estimate before a spare is added for any Item j and $AEI(s_j)$ is the estimate after the spare is added and f is the system impact factor, we have the following:

$$AEI(s_j - 1) = 1 - \sum_{i=1}^{N} f\ (EBO_i) = 1 - f\ [EBO_j(s_i - 1)] \sum_{i=1,\ i \neq j}^{N} (EBO_i),$$

and

$$AEI(s_j) = 1 - (f)\ [(EBO_j(s_j)] \sum_{i=1,\ i \neq j}^{N} (EBO_i).$$

Hence, the difference between the two AEIs is given by

$$\Delta AEM(s_j) = [1 - (f)\ EBO_j(s_j)] - [1 - (f)\ EBO_j(s_j - 1)].$$

This simplifies to

$$\Delta AEM(s_j) = f\ EBO(s_j - 1) - EBO(s_j).$$

Glossary

Glossary

AAM	=	Aircraft Availability Model
AAW	=	antiaircraft warfare
ACIM	=	Availability Centered Inventory Model
ACWT	=	average customer waiting time
ADD	=	average depot delay
A_i	=	inherent availability
AMSAA	=	Army Materiel Systems Analysis Activity
A_o	=	operational availability
ARROWs	=	Aviation Readiness Requirements Oriented to Weapons
ASL	=	authorized stock list
ASUW	=	antisubmarine warfare
ASW	=	antiship warfare
AVCAL	=	aviation consolidation allowance list
CARES/SPA	=	Computation and Research Evaluation System (Navy)/Supply Performance Analyzer (Army)
CB	=	chemical-biological
CIWS	=	Close-in Weapon System
COSAL	=	coordinated shipboard allowance list
C^3	=	communication, command, and control
DLA	=	Defense Logistics Agency
DoDAAC	=	DoD Activity Address Code
DoDI	=	DoD Instruction

DSU	=	direct support unit
DTIC	=	Defense Technical Information Center
EBE	=	expected number of backorders established
EBOs	=	expected backorders
EOQ	=	economic order quantity
GAO	=	General Accounting Office
ICPs	=	inventory control points
JCS	=	Joint Chiefs of Staff
JLSC	=	Joint Logistics Systems Center
LDT	=	logistics delay time
LMI	=	Logistics Management Institute
LRUs	=	line replaceable units
MCS	=	maneuver control system
MLDT	=	mean logistics delay time
MLRS	=	Multiple Launch Rocket System
MLRT	=	mean logistics response time
MOTBF	=	mean operating time between failures
MSDT	=	mean supply delay time
MSRT	=	mean system response time
MTBF	=	mean time between failures
MTTR	=	mean time to repair
NSO	=	numeric stockage objective
NW	=	number of weapons
PC	=	personal computer

PLL	=	prescribed load list
PMR	=	provisioning master record
QFD	=	quarterly forecasted demand
QPA	=	quantity per application
RBS	=	readiness-based sparing
RD&ES	=	Requirements Determination and Execution System
SBSS	=	standard base supply system
SD	=	standard deviation
SEBO	=	sum of EBO
SESAME	=	(Dynamic) Selected Essential Stockage for Availability Method (Army)
SINCGARS	=	Single Channel Ground-Airborne Radio Subsystem
SL	=	safety level
SMR	=	source, maintenance, and recoverability
SORTS	=	status of resources and training system
STA	=	sparing-to-availability
TIGER/ACIM	=	Tiger/Availability Centered Inventory Model
VMR	=	variance to mean ratio
WRAs	=	weapon replaceable assemblies
WSIC	=	weapon system indicator code
WSSP	=	weapon system support program

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13. ABSTRACT *(Maximum 200 words)*

The Joint Logistics System Center is developing the "Multi-Link" system as an alternative that the Services and the Defense Logistics Agency (DLA) can use to implement the readiness-based sparing concepts directed by the Office of the Secretary of Defense. This study considers the primary issues which arise if DLA were to use Multi-Link, and proposes a strategy for DLA The key element of this strategy is that line replaceable units (LRUs) become the focus of DLA's weapon system program so that DLA will know the items that have the most direct impact on weapon system availability. Our research indicates that properly identifying the LRUs is crucial to using Multi-Link. DLA managed LRUs, cost much less than Service managed LRUs, so that a trade-off model like Multi-Link calls for more stock of the cheaper DLA items, and less stock of the costlier Service items. However, since DLA consumable LRUs are more difficult to identify than Service LRUs, including DLA items in a Multi-Link trade-off must be done cautiously. Therefore, our recommended strategy is that DLA manage the weapon system LRU to higher wholesale performance goals than other items until the Services tell DLA which items to manage via Multi-Link.

14. SUBJECT TERMS

DLA, Defense Logistics Agency, inventory, JLSC, Joint Logistics System Center, LRU, line replaceable unit, multi-echelon, multi-indenture, Multi-Link, operational availability, RBS, readiness based sparing, weapon system, wholesale response time, wholesale stock availability.

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